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DESIGN, DEVELOPMENT, UPGRADING AND TESTING OF THE EXISTING MARINE RADAR IMAGE DISPLAY SYSTEM FOR AN ICE NAVIGATION WORKSTATION

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Un sommaire en français de ce rapport est inclus avant la Table des matières.

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17. Abstract

This report describes the upgrading and testing of two systems which are to be used together in an integrated display for ice navigation. The first such system is an airborne downlink receiver/user workstation called STAR-VUE. The second system is an advanced marine radar display for ice imaging called MARINE-VUE. The upgrades to these systems are described, results of shipboard trials reported and laboratory research projects outlined.

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17. Résumé

Ce rapport décrit les travaux de perfectionnement et les essais de deux sous-systèmes d'affichage devant être intégrés dans un poste de navigation dans les glaces. Il s'agit, d'une part, du sous-système STAR-VUE qui agit comme poste récepteur de l'information radar aéroportée et comme station d'utilisation et, d'autre part, du sous-système avancé appelé MARINE-VUE qui affiche l'information glaces fournie par le radar de bord. Les travaux de perfectionnement, le résultat des essais à bord et la proposition d'un programme de recherche en laboratoire sont présentés dans ce rapport.

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SUMMARY

The growing commercial development of northern offshore frontier areas and an increase in vessel traffic in the Gulf areas have resulted in the need for better, more reliable ice information for improved marine transportation. The Transportation Development Centre (TDC) Transport Canada has undertaken an extensive research and development program with INTERA Technologies to develop new systems for navigating in ice by using advanced radar systems. This report describes the development of an integrated shipboard system called NAV-ICE that uses airborne radar along with marine radar, for strategic and tactical ice navigation.

The primary objective of this program was to upgrade and evaluate the marine radar and airborne radar display systems. Specifically, the work focussed on the design, development and testing of new software modules for the existing radar downlink receiver called STAR-VUE in order to make the system more suited to the task of ice navigation. In addition, several marine radar display systems were modified, tested and evaluated.

The activity described here conducted during the period of August 1985 to September 1986.

The modification to the STAR-VUE system included the addition of a course and distance function, a function to track the ship's progress, an update to the map data base function, the addition of a north arrow for navigation, a hardcopy output facility and a mosaicing function design. The MARINE-VUE developments included the testing of signal processing functions which were added to INTERA's Radar Image Display System (RIDS) and the complete testing of a new radar display system manufactured by Folsom Research Inc.

As a result of this work the STAR-VUE system is now operational and suitable for ice navigation. However, there is a strong demand from navigating offices for ready access to a completely annotated display system, i.e., to include a latitude and longitude grid on the imagery. The implementation of such a system must wait for the development of the aircraft segment before this can be achieved.

During the time frame of this project, several radar display systems have been tested and evluated. It was determined that the RIDS system would have to be redesigned to perform the majority of its functions in hardware. This, however, would require a major redesign and equipment build. During the summer of 1986 a new radar scan converter manufactured by Folsom Research Inc. was tested on the M.V. Arctic. The Folsom unit was found to be a much higher quality display unit than the RIDS or the JRC units, which were used for comparison. This is because the Folsom unit displays every radial pulse and writes an extremely high quality display result into memory. In addition, the

Folsom unit has a standard computer interface which can be controlled from the STAR-VUE host computer. Both control signals and data can be exchanged. A menu system was developed for the STAR-VUE to control the Folsom unit for this program.

The Folsom unit proved to the best available display unit for MARINE-VUE but several of the standard marine radar controls and functions were found to be lacking. Many of these features will be added to the system by the manufacturer. Others will require further development.

SOMMAIRE

L'accélération de l'exploitation économique des régions septentrionales du Canada et l'intensification de la navigation maritime dans le golfe du Saint-Laurent ont mis en évidence le besoin d'aides à la navigation dans les glaces, plus fiables et de meilleure qualité. Dans cette optique, le Centre de développement des transports de Transports Canada et la firme INTERA Technologies ont conjointement lancé un programme ambitieux de recherche et de développement sur des systèmes avancés de navigation radar. Le présent rapport décrit les résultats de la recherche sur un poste de navigation intégré et embarqué, appelé NAV-ICE, qui utilise l'information transmise par les radars aéroportés ainsi que le radar de bord pour fournir des prévisions à court et à long terme.

La recherche avait pour objectif principal d'améliorer les performances des sous-systèmes d'affichage de l'information radar et d'évaluer les résultats. Elle s'est attachée plus particulièrement à la conception, à la mise au point et à l'essai des nouveaux logiciels destinés au poste récepteur existant appelé STAR-VUE que l'on veut rendre mieux adapté à la navigation dans les glaces. En outre, divers autres systèmes d'affichage de l'information radar de bord ont été modifiés, essayés et évalués.

Tous les travaux décrits dans ce rapport ont eu lieu entre août 1985 et septembre 1986.

Les fonctions ajoutées au sous-système STAR-VUE ont été les suivantes: calcul des distances et des relèvements; repérage du navire sur l'imagerie radar; mise à jour de la base de données cartographiques; indication du nord; sortie sur papier. Les chercheurs ont également étudié une fonction de production de mosaiques. Pour ce qui est de MARINE-VUE, il a été procédé à l'essai du système RIDS (Radar Image Display System) amélioré, incorporant des fonctions de traitement des signaux, et aux essais complets du nouveau système d'affichage radar fabriqué par la Folsom Research Inc.

Tous ces travaux ont amené le sous-système STAR-VUE au stade opérationnel et l'on rendu apte à la navigation dans les glaces. Toutefois, les officiers de navigation veulent maintenant avoir à leur disposition un système d'affichage avec annotations complètes, c'est-à-dire incorporant un quadrillage (longitudes et latitudes) à l'imagerie; mais ceci ne pourra se faire avant la mise au point de la partie aéroportée du système.

Divers systèmes d'affichage de l'imagerie radar ont été essayés et évalués dans le cadre de l'étude. Il a été déterminé que, pour accélérer le fonctionnement du RIDS, il faudrait que la plupart de ses fonctions soient réalisées en câblé, ce qui sous-entend d'importants travaux de réétude et de fabrication. A l'été de 1986, un nouveau convertisseur de balayage fabriqué par la Folsom Research Inc. a été essayé sur le N.M. Arctic. Ce dispositif s'est révélé supérieur tant au RIDS qu'au matériel JRC utilisés comme témoins. Ceci s'explique par le fait que toutes les impulsions radiales reçues sont affichées et mémorisées, produisant un affichage de

très haute qualité. De plus, il possède un système d'interfaçage standard qui permet de le commander à partir de l'ordinateur central du STAR-VUE. Des signaux de commande et des données peuvent donc être échangées. Un menu a été étudié permettant au STAR-VUE de commander le convertisseur Folsom aux fins du programme.

Le matériel Folsom a, par ailleurs, convenu au sous-système MARINE-VUE mieux que tous les autres, mais il lui manque encore plusieurs des commandes et fonctions qui sont standard sur tous les radars de bord. Certaines seront ajoutées par le fabricant, tandis que d'autres devront attendre des perfectionnements ultérieurs.

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1. INTRODUCTION

With the growing commercial development of the northern offshore frontier areas and the growth of mining and other land-based activities in the high Arctic, a need has arisen for better and more reliable information on ice conditions for improved marine transportation. The use of remotely sensed data, particularly airborne radar (side-looking airborne radar (SLAR) and synthetic aperture radar (SAR)), has expanded rapidly in recent years so that it is now possible for marine operators to obtain reliable all-weather information on ice conditions and hazards, even in the darkness of the Arctic nights. Transportation Development Centre (TDC), Transport Canada, has undertaken this extensive research program with INTERA to study new techniques for Arctic marine operations in ice using airborne radars. This report describes the development of an integrated shipboard system called "NAV-ICE" that primarily uses airborne radar along with marine radar imagery for strategic and tactical ice navigation.

The activity described in this report was conducted during the period of August 1985 to September 1986. During this period, many technological changes were incorporated into the NAV-ICE system. Numerous field trials were undertaken using the M.V. Arctic as a research platform to test out these developments.

The primary objective of this program was to upgrade and evaluate the marine radar and airborne radar display systems as part of an improved, safer ice navigation system. Specifically, the work focused on the design, development and testing of new software modules for the existing radar downlink receiver called STAR-VUE in order to make the system more suited to the task of ice navigation. In addition, several marine radar display systems were modified, tested and evaluated in order to determine their suitability for the NAV-ICE system.

1.1 Background

The work described here stems from an earlier TDC-sponsored program called MIDAS (Multi-task Ice Data Analysis System).

The overall objective of the MIDAS program was to develop an integrated facility that is capable of providing both strategic and tactical level information on ice conditions for ships and offshore drilling vessels operating in the Arctic and other ice-infested waters.

Those operators requiring such ice information include: ice breakers and ice breaking tankers capable of year-round operations; lightly ice-reinforced vessels (Arctic class IV or less) not capable of unrestricted year-round operations; and oil and gas industry-related drilling and production platforms. Their operational areas are the Western Arctic including the Beaufort, Chukchi and Bering seas, the Central Arctic including the Arctic Islands and the Northwest Passage, and the Eastern Arctic extending from Baffin Bay to Newfoundland.

The experience gained by INTERA, Canarctic, Dome and other organizations engaged in Arctic sea operations has shown that real-time ice information which is available from sources like airborne radars (SAR, SLAR), marine radars and satellites (IR/visual) can be used for better route planning and tactical navigation by ships in transit. With a knowledge of the ice conditions in an operational region, a ship's Master can optimize his route and avoid areas where the risk of contact with ice (or at least heavy ice) is great. The resulting savings in ship operating costs, vessel damage, and improved delivery schedules have proven to be very substantial.

MIDAS was a shipborne facility that utilized remotely sensed data for close range hazard detection and for strategic and tactical ice navigation. This system made it possible to selectively route a vessel through an ice field, minimizing contact with the ice encountered. The successful demonstration of the utility of these remotely sensed data for ice navigation has greatly influenced thinking on marine operations in the Arctic.

The Canarctic Shipping Company Limited has also undertaken research programs to develop new techniques for navigating in ice. Canarctic owns and operates the M.V. Arctic, a Canadian-built Class 2 icebreaking bulk carrier. Both Canarctic and INTERA have been working over the last two years to develop more integrated ice information systems to be used on commercial icebreaking ships. Canarctic has pioneered work on ice hazard detection systems and ice navigation techniques using remotely sensed data under a program titled "SINSS" (Shipboard Ice Navigation Support System). INTERA has focused on developing integrated shipborne display systems that currently use both airborne radar and marine radar imagery for ice navigation (NAV-ICE).

1.2 The MIDAS Project

During the course of the MIDAS project, three field operations were undertaken to provide the necessary information for a detailed system design. All of these operations were carried out onboard the Arctic class 2 ore carrier the M.V. Arctic - a facility provided by Canarctic and judged to be ideal for this study. The analysis of these operations resulted in a detailed user requirements document and specification for MIDAS.

One of the key concepts to emerge from this early research is that of an "ice navigation chart". Typically, navigators have charts of the world's oceans; however, what is required for operations in the Arctic is a similar chart showing detailed ice conditions over a fairly large region. This requires superior information to that which has been available in the past. Features such as old ice and icebergs with sizes of the order of 10 metres should be shown on the chart. Areas of ice rubble, ice build up and ice compression also need to be shown. Because ice conditions change rapidly, this information must also be available in real-time. It has been demonstrated that airborne SAR imagery like that available from INTERA's STAR-1 provides the right image characteristics and the right level of information to be used as an ice navigation chart. It is also easily interpreted by ship's officers. By staging periodic airborne radar missions, geographically annotated airborne radar data can be telemetered to the bridge of a ship in real-time and then used for navigation. The ship's marine radar provides the means for tracking the position of the ship on the SAR imagery when ice conditions have changed.

The MIDAS research has also pointed out that interpreted ice charts like those currently produced by AES are unsuitable for this task of tactical navigation.

1.3 Description of Airborne Radar Systems

Before discussing MIDAS further, the airborne radar systems which have been used by INTERA to determine the requirements for the integrated ice information system (NAV-ICE) are described. INTERA operates both commercial SAR and SLAR systems.

A normal SLAR system can be thought of as a marine radar system pointed downwards instead of outwards. As the aircraft flies in a straight line, two swaths, one to either side of the aircraft, are imaged. There is a dead zone underneath the aircraft of width about twice the aircraft altitude. The SLAR system used by INTERA is a Marine Airborne Patrol Radar (MAPR). The MAPR system is mounted in a Cessna Conquest 441 aircraft and is capable of simultaneously imaging a swath of either 25 or 50 km on both sides of the aircraft. It is a digital radar, hence radar returns are processed digitally and recorded for subsequent analysis.

As in a conventional radar, the resolution of a SLAR is a function of range from the aircraft. For the MAPR, this varies from about 40m in the near edge of a swath to about 200 m at the far edge of a 25m-wide swath. The signal return is also a function of the angle of incidence of the radar signal. At low angles of incidence, the percentage of radiation backscattered begins to fall off, limiting the information that can be deduced from the signal. Also, the "texture" of the return signal will vary across a swath width due to the change in the angle of incidence.

While the SLAR is described as being a marine radar looking sideways, a SAR or Synthetic Aperture Radar could be described as a dramatically upgraded SLAR. The resolution of a SAR is improved by post processing the return signal. A doppler history is recorded for a target as the aircraft passes by, and through the use of a technique called doppler compression, a point image is created from that doppler history. The result is that the resolution of a SAR is independent of range.

The SAR system used in the studies described here is the INTERA STAR-1 (Sea-ice and Terrain Assessment Radar). The STAR-1 features full digital processing in a lightweight package which is flown in the same small turbo-prop Cessna as the MAPR system. Because the STAR-1 is digital, the radiometric properties of the image are much more easily controlled than with a SLAR. The result is that not only is resolution constant across a swath, but the characteristics of the image across the track width are also nearly constant. This latter characteristic makes it much easier to use a radar such as STAR-1 for interpretation of ice conditions than to use a conventional SLAR.

The STAR-1 images one swath at a time, to one side or the other of the aircraft. Swath widths can be either 25 km or 50 km. The resolution in the narrow high resolution swath mode is 6 x 6 m; the resolution in the wide mode is 12 x 12 m.

The data collection mode is similar for both radars. Once a survey area is selected, a series of flightlines are set up that provide full coverage of the area. In the case of the SLAR, flightlines are staggered so that the dead zone underneath the aircraft during a flightline is covered by a subsequent flightline. In the case of STAR-1, succeeding flightlines are simply moved left or right to provide full coverage.

The need for a high resolution, wide swath, economical airborne radar system designed to support Arctic marine operations was recognized a number of years ago by INTERA. This resulted in the STAR-1 system. It has proven to be an invaluable tool for the drilling operations in the Canadian Beaufort, with all of the major oil companies subscribing to the flight service provided by INTERA. This service has been extended recently into the American Beaufort for drilling rigs and seismic ships. STAR-1 has also supported Canarctic's vessel, the M.V. Arctic, on its voyages to the Eastern Arctic, which resulted in substantial savings both in terms of travel time and fuel costs for the vessel.

It has been shown that airborne SAR can be used by ship's personnel for strategic planning by mapping large areas on the order of hundreds of kilometers. If the resolution is high enough, this same information can be used for close range hazard avoidance. INTERA's STAR-1 SAR typically images a ground swath 50 km in width, and the endurance of the aircraft is such that large areas, such as Baffin Bay or Lancaster Sound, can be mapped during a single mission. This information can then be downlinked to a ship in near real-time via a radar link from the aircraft. For a 50-km swath, the resolution of the ground pixels is 12 metres by 12 metres, which is suitable for close range hazard avoidance.

1.4 The Need for Ice Information

Ships operating in ice require high resolution data that can be presented on the order of metres if they are to successfully avoid the hazards along their route. This information must be continuously available to the ship's officer in sufficient detail to steer the ship. Besides the resolution requirement, it must be possible to distinguish such features as individual pressure ridges or rubble areas and old ice floes or small icebergs in first-year ice.

The traditional method of navigating in ice utilized visual observations from the ship itself or an aircraft with help from marine radars. The visual methods are limited to daylight and good weather and the marine radar can be limited by the problem of interpreting what it shows.

1.5 The MIDAS Design

There were essentially two tasks to be accomplished by MIDAS. First, a ship must be able to select the optimum route, which normally means minimizing the ice encountered, both in quantity and severity. Second, once a route is chosen, the system must be able to show the location of all the exceptional hazards on that route. The proposed baseline MIDAS system consisted of the following four components:

1) A system capable of automatically receiving and storing and interactively displaying airborne radar data. INTERA was designing and building such a system, called STAR-VUE. STAR-VUE is a microcomputer-based system which serves as both a receiver and user workstation;

2) A marine radar display system which is capable of displaying both real-time and "enhanced" marine radar data on bright TV-type displays;

3) A system or number of systems capable of receiving conventional ice and weather charts and real-time satellite imagery. Because of the communication problems encountered in the Arctic, real-time satellite products are very valuable for strategic support. A number of commercial systems are now available which receive ATP data from the NOAA polar orbitting satellites; and

4) A communications interface between these systems.

2. PROPOSED DEVELOPMENT

The MIDAS project generated a detailed requirements document and functional specification for a shipborne ice navigation system. The core of this system, however, is the marine radar display system and an airborne radar display/user workstation. As a result of the MIDAS program, INTERA proceeded to develop a downlink receiver/user workstation called "STAR-VUE" to be used for the display and analysis of airborne radar data. This system was developed as a commercial product with a wide range of applications for SAR and SLAR data.

Although it was not designed specifically for "marine navigation", it incorporates many of the functions required for an ice navigation system. These include: the reception of airborne radar data, the capability of displaying full resolution data at more than one scale on more than one display, and the capacity to store these data on magnetic media for quick recall or for archival purposes.

Close tactical navigation requires that the operator of the ice navigation system locate the position of the ship on the SAR mosaic with the marine radar. This requires a bright TV-type display for the marine radar data. The requirements for the operation of this marine radar display system were also outlined in the MIDAS report, which stated that there were currently no commercially available systems that were designed for imaging ice. INTERA's RIDS was designed as an ice imaging radar system; however, it was designed for use on stationary drillships. Its consequent slowness made it less than desirable for use on a rapidly moving ship. Thus there were two systems, in INTERA's opinion, which required further research and development. These were:

1. The development of the airborne radar downlink receiver/user workstation to be used for ice navigation; and

2. The development of an advanced marine radar display for ice imaging.

These systems would be used together in an integrated display system for ice navigation and hence called NAV-ICE.

2.1 STAR-VUE Development

The new downlink receiver/user workstation being built by INTERA (STAR-VUE) was not designed specifically for navigation in ice, even though it performed many of the functions required by such a system. STAR-VUE was basically an image display system designed for a variety of users including stationary drilling operators and icebreaking tankers. There were, however, several functions which could be added to STAR-VUE to make it better able to handle the job of navigation in ice. Many of these functions were outlined in the MIDAS study. These include functions that allow the operator to interactively select waypoints, as appropriate, on the radar imagery for route planning, obtain range and bearing information from targets on the imagery, and record the ship's track on the imagery. STAR-VUE was designed so that these functions could be added to the software base. It was therefore proposed to TDC that the software for these functions be designed, developed, evaluated, and if practical, incorporated into the STAR-VUE system. Close attention had to be paid to the user interface so that the system functions could easily fit into the STAR-VUE conceptual model and be easy to ue by non-computer professionals. Secondly, INTERA proposed to Canarctic that they support the field testing of the STAR-VUE system prototypes.

2.2 Marine Radar Development

During the MIDAS program, it was shown that marine operators can use the ship's own marine radar display system to locate the position of the ship in SAR imagery. INTERA's RIDS system was used for this purpose.

INTERA's RIDS was designed as a bright display for imaging ice from stationary drillships. Its consequent slowness made it less than desirable for use on a rapidly moving ship.

In June 1985, INTERA recommended that Canarctic lease a commercial radar display (JRC) and interface this to the ship's Decca radar. This system provided a bright real-time display.

It was proposed to TDC that a second marine radar display system be installed onboard the M.V. Arctic. This system was the INTERA RIDS, which was to be modified to improve the display of ice information.

The RIDS system was also to be used for comparison with the JRC display. RIDS modifications were to include a speed increase, an analogue range dependent gain function, scan averaging, and a real-time data logging function.

The RIDS system was to be connected to both the ship's X-band radars under the terms of another contract with Canarctic.

3. STAR-VUE DEVELOPMENTS

3.1 Background

Modern high density electronics have allowed a new generation of airborne SLAR and SAR systems to be developed with real-time processors onboard aircraft that generate imagery in real-time. Typical of these systems are the INTERA SLAR and the INTERA SAR which can detect significant ice features such as open water, first-year ice, old ice, rubble fields and icebergs. With regular reconnaissance and some detailed knowledge of the ice climatology, many secondary features can also be inferred such as thickness, convergence, speed of motion, etc.

While the value of ice imagery has been obvious from at least the time of the voyage of the Manhatten (1969), there was a real problem in distributing the data to the users at work in the ice. The imagery was recorded onboard the aircraft and a hardcopy record produced for quality control. The aircraft would then have to land to deliver these data tapes and hardcopy. While much useful work can be done with these data in the way of operational planning, ice information can age very quickly and delays incurred in getting the data to base and back to the actual users were clearly unsatisfactory. Not only was the process slow, but the information sent by verbal or fax transmission would obviously be inferior to the original detailed image.

The first downlinking experiments conducted by INTERA and Dome (Mercer et al. 1980) used the SAR-580 imaging radar, which then had a real-time SAR image, covering a swath width of some 6 km. The downlink hardware consisted of a TV camera and light table, a slow-scan TV transmitter and receiver and a standard aircraft VHF radio link. On the ship, the signal was received as an audio signal taped and fed into the slow-scan TV unit. A hardcopy unit was used to copy this image to dry silver paper. The speed and image quality of this system were not ideal, but the process demonstrated that real-time SAR could be used to direct icebreakers to break up ice before they impacted a drillship. This led to the development of high quality downlink hardware for the following year.

For the 1980 experiments, a full digital downlink was developed. This took the digital imagery directly from the SAR processor, encoded it and transmitted it to the ground on a phase shift keyed, FM modulated 219.5 MHz carrier, using a 256 Kbit/sec clock. The data were recorded on a standard 9-track computer tape, and imagery was produced using a fiber optic printer onto 23-cm wide dry silver paper in a continuous strip format. This made it possible to produce multiple copies of the high quality SAR image on the ground. This system has been in constant use since 1980, with a variety of SLAR and SAR systems.

When STAR-1, INTERA's SAR, was introduced, a higher rate downlink was developed, based on the same carrier frequency (219.5 MHz) but using a quadrature phase shift keyed (QPSK) 1.4 Mbit/sec modulation scheme. This required a High Density Digital Tape (HDDT) to record the data. Again, the display is on film using a 23-cm wide continuous strip film. Either dry silver paper or transparency can be used, or, if darkroom facilities are available, a wet chemically developed film can be used for the best quality imagery.

Figure 1 shows a block diagram of a generic digital downlink system. Data are created in an image format onboard the aircraft, stored on magnetic tape and simultaneously made available at the downlink. With digital radars, the format is usually one scanline per record with each pixel represented by 4 or 8 bits of grey scale information. These data are usually in a parallel format, and must be reformatted for transmission as a serial stream (one bit at a time). Once the data are in serial form, it is necessary to separate lines by inserting framing information. Once this has been done, the digital stream is ready to send by modulating it on an RF carrier, and broadcasting.

The received signal is first demodulated and turned into a serial bit stream, with a clock signal which is derived from the bit stream. The framing information is then detected, and this data stream is fed to a serial to parallel converter. The data are now fully reformatted and exactly match the data at the output of the imaging radar. They can be displayed and recorded as appropriate.

The main drawback with hardcopy-based downlinks is the requirement for continuous attention during their use by a relatively skilled operator. The most time-consuming task is the production of the quality film product. For this reason, the systems tend to be less than popular unless a motivated and dedicated operator is available. However, they do allow users access to the same quality imagery on the ground as that which is available in the aircraft, in real-time. For ice operations, this timeliness has proven very useful.

The problems associated with the hardcopy downlink described so far had become clear from INTERA's field operations and experiments carried out for TDC on the M.V. Arctic during the MIDAS study. This system was clearly not designed for use on ships. The STAR-VUE system has thus been developed to receive and display downlinked radar imagery in a more convenient fashion.

STAR-VUE is a computerized system which replaces the existing ground receiver station for the downlink. Data transmitted from the aircraft are automatically recorded on disk. The system allows the recall of current or previous radar imagery for display on a high resolution monitor. With the aid of a trackball, any section of the main image may be displayed in an expanded form. The selected display may also be output to a hardcopy device if a permanent record is required. Much thought has gone into ensuring STAR-VUE is simple to use. The trackball controls all operations, thus no keyboard operations are required. The system is intended to be used by a person with no previous exposure to computer systems.

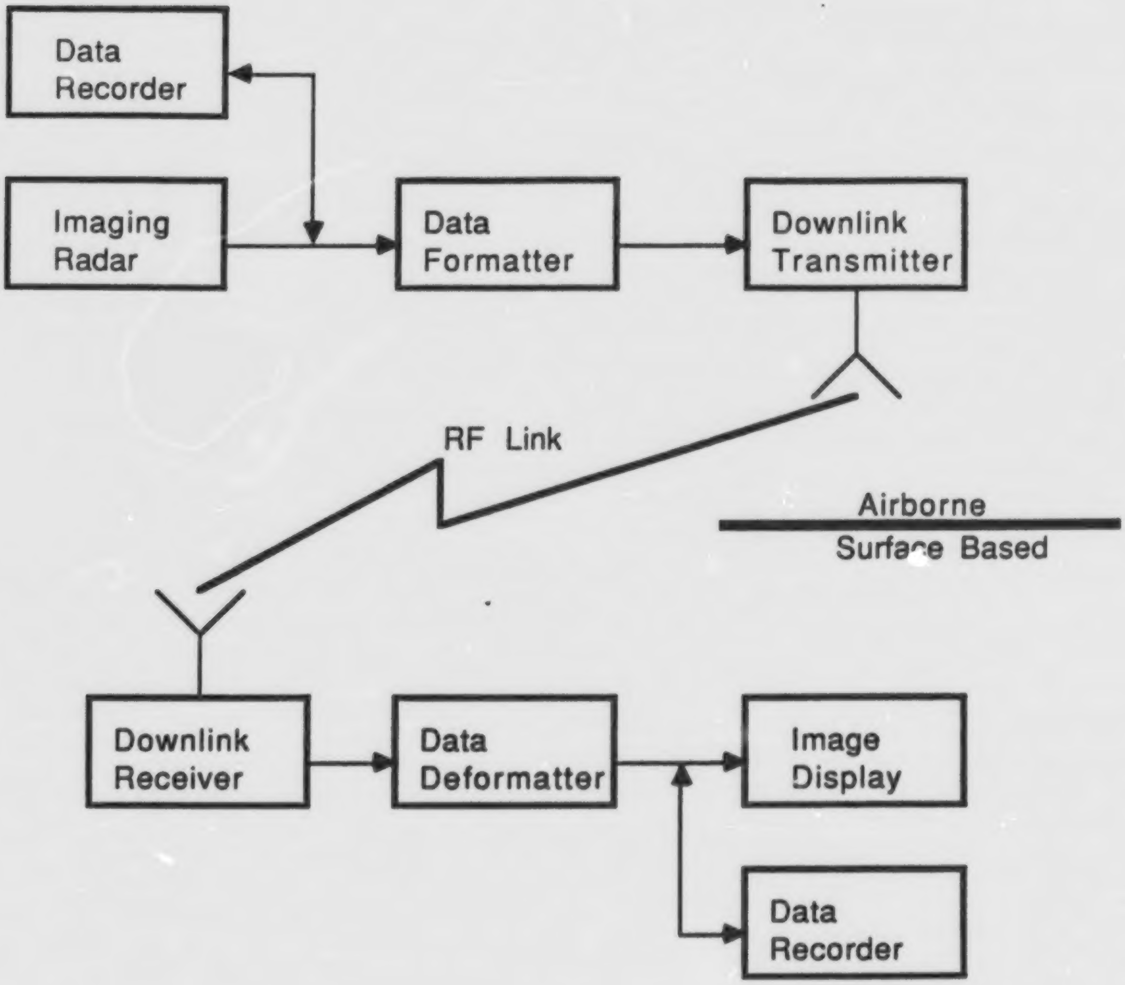

Data Recorder
Imaging Radar
Data Formatter
Downlink Transmitter
RF Link
Airborne
Surface Based
Downlink Receiver
Data Deformatter
Image Display
Data Recorder

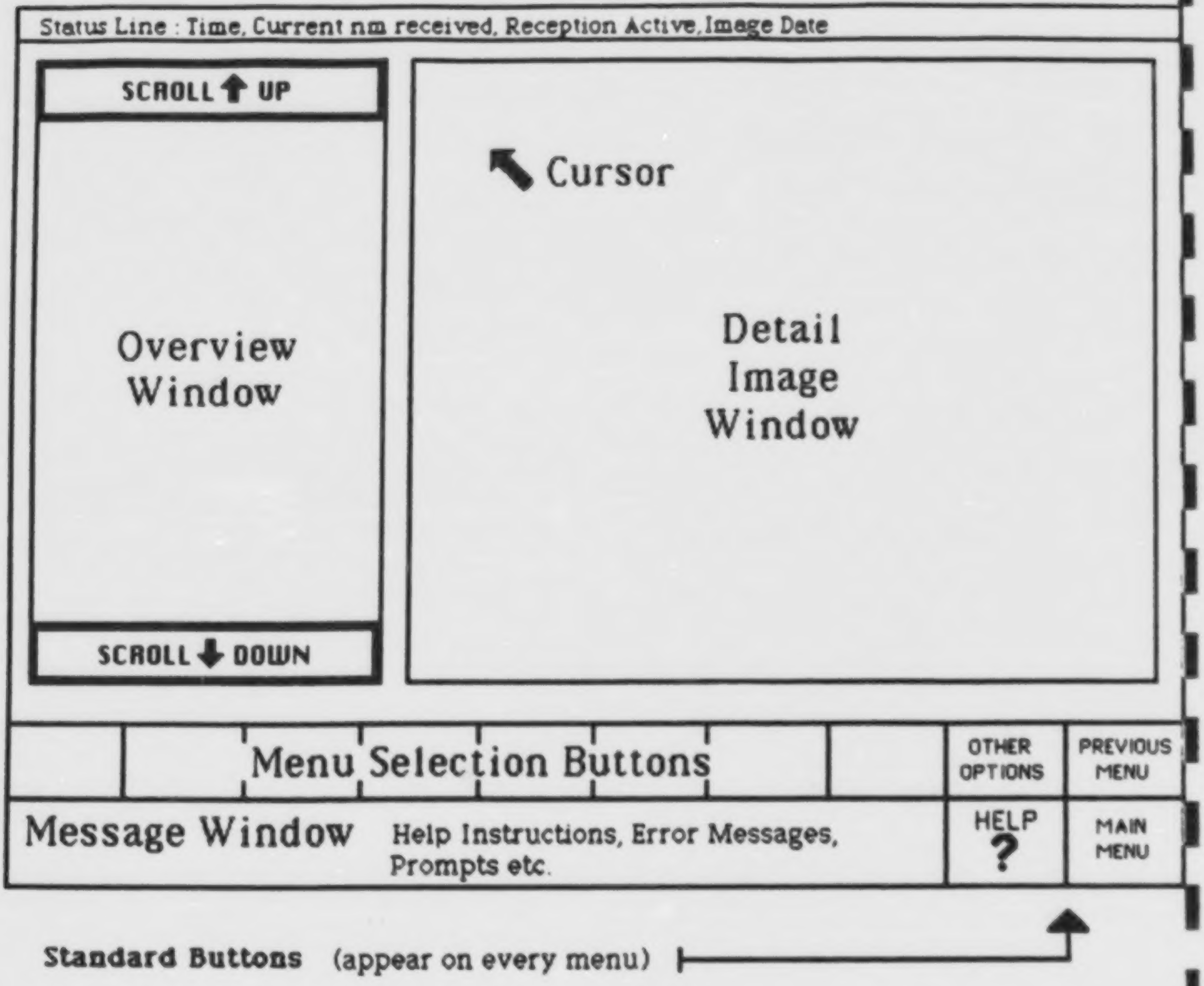
Figure 1 Block diagram of a generic downlink system.

3.2 System Design

The STAR-VUE system has evolved as a direct result of the work described in this report. During this project, prototype systems were developed, many discussions with end user and equipment suppliers held, and shipboard trials carried out. Mock-up displays were created to obtain user reaction to the softcopy display options. The user model was considered very carefully during the development of the STAR-VUE system. STAR-VUE was designed to be used by ships' officers who had experience with ships in ice but had little or no computer experience. It was expected that someone aboard the vessel would have a short (1- to 3-day) course on the system, but that the majority of the users would be trained "in the field". The system would be used jointly by the commanding officer, the duty watch officer and an ice observer or any combination. As well, it could easily be unattended at any time.

The shipboard environment for the system was also considered and found to be somewhat hostile. No software specialists or electronic technicians were imagined to be on the vessel. Any hardware maintenance would have to be at the "board swap" level. However, the vessel would be periodically in port, at which time technicians could do routine maintenance. The environment on the vessel was considered to be similar to a shop floor, with more dust than an office, some residual salt spray, and potential for 1-2 g over the frequency band 0.1 to 10 Hz, which is not uncommon on icebreakers. Power of nominal 110/220 V @ 50/60 Hzis normally available; however, variations of both frequency and voltage are common. While normal operation may not be demanded with corrupted power, the system must be able to survive the fluctuations. The tasks required of the system were considered in detail before system development began. First, the system was required to receive and store imagery independent of operator intervention. The storage medium was to be on-line and have random access. The data, when stored, were to be accessed by the user from a geographical data base. Sailors are very familiar with maps, and therefore a map-like data catalogue was designed. By recording the lat/long of the aircraft at the ends of each pass and knowing the geometry of the radar, an image of the flightline on a map became the icon by which a user could access the data on that file.

Early on in the design of the system, it became apparent that to have a softcopy display replace a hardcopy system, the softcopy display would have to emulate the required features of the hardcopy system. One of the great advantages of hardcopy is that simply by standing back, a fine resolution image can be converted to an overview image. It was clear from observing users of tactical radar imagery that this feature would be required. This implies much more than a zoom and roam capability, as both the overview and the zoom image are required at the same time. The solution to this has been to segment the display into two windows (Figure 2). One display window shows a very large area such as an entire flightline or mosaic of flightlines. This is known as the Overview Window. By roaming a box cursor over the overview, and


Status Line : Time, Current nm received, Reception Active, Image Date
SCROLL UP
Overview Window
SCROLL DOWN
Cursor
Detail Image Window
Menu Selection Buttons
OTHER OPTIONS
PREVIOUS MENU
Message Window
Help Instructions, Error Messages, Prompts etc.
HELP ?
MAIN MENU
Standard Buttons (appear on every menu)

Help ?	help cursor appears; next pick gets info
Main Menu	return to the primary menu
Previous Menu	return to the parent menu
Other Options	pop-up menu for other secondary choices

Figure 2 Diagram of the STAR-VUE display showing the overview, detail, message and control windows.

increasing or decreasing the size of the box, an area of the image can be selected for enlargement. This enlargement appears in the second window, which is called the Detail Window.

3.3 System Description

3.3.1 Airborne Portion

The STAR-1 SAR has been described elsewhere, but the data format, particularly as it appears at the downlink output, has not. The image, as it issues from the RTP (Real-time Processor), consists of scanlines of 4096 pixels, 1 pixel per byte. The lines are spaced 4.2 m in the along-track dimension and the pixels are spaced approximately every 6 or 12 m (in high resolution or wide swath mode) in the across-track dimension. These data are recorded on High Density Digital Tape (HDDT) and on a hardcopy device. The downlink formatter accepts these data and converts them to a form suitable for transmission. For some applications, this requires a full bandwidth downlink, and a 1.4 Megabit/sec system has been developed to accomplish this. However, for ice application, the experience to date has led to the reduction of the data rate by averaging lines and/or pixels and reducing the number of bits to 4 from 8. This has been shown to be adequate for nearly all ice reconnaissance tasks (Lowry et al. 1984).

Each line of the STAR-1 data output is now annotated with 64 bytes of radar status and aircraft location data. This includes a line count for verification of scale at the earth station in the face of potential dropouts on the radio link.

After the data have been reduced to 5 bits/pixel and the line rate reduced, they are suitable for transmission on the 256 Kbit/sec downlink. The data are first converted from parallel to serial form and a start code is introduced for modulation on the carrier (219.5 Mhz). The resultant signal is broadcast on an antenna with a near isotropic pattern.

Changes in radio frequency allocation since the WARC '69 agreement have forced consideration of higher frequencies. The result is a move to S-band, at least for areas outside the high Arctic. Although the radio link can be seen as a separate part of the downlink (i.e., the piece of wire), the change to S-band does affect the cost at both the transmission and receiving end of the system rather dramatically.

3.3.2 Shipborne Portion

The hardware in the earth station end is sketched out in Figure 3. The RF link delivers the serial bit stream to the STAR-VUE Receiver Interface Board (SRIB) via an antenna and an RF receiver. As mentioned above, this is currently at 219.5 Mhz but could theoretically be at any frequency that is required, although not necessarily at the same cost. The SRIB plugs into the backplane of the host computer from which it draws power, but communicates only to Communications Coprocessor (CC).

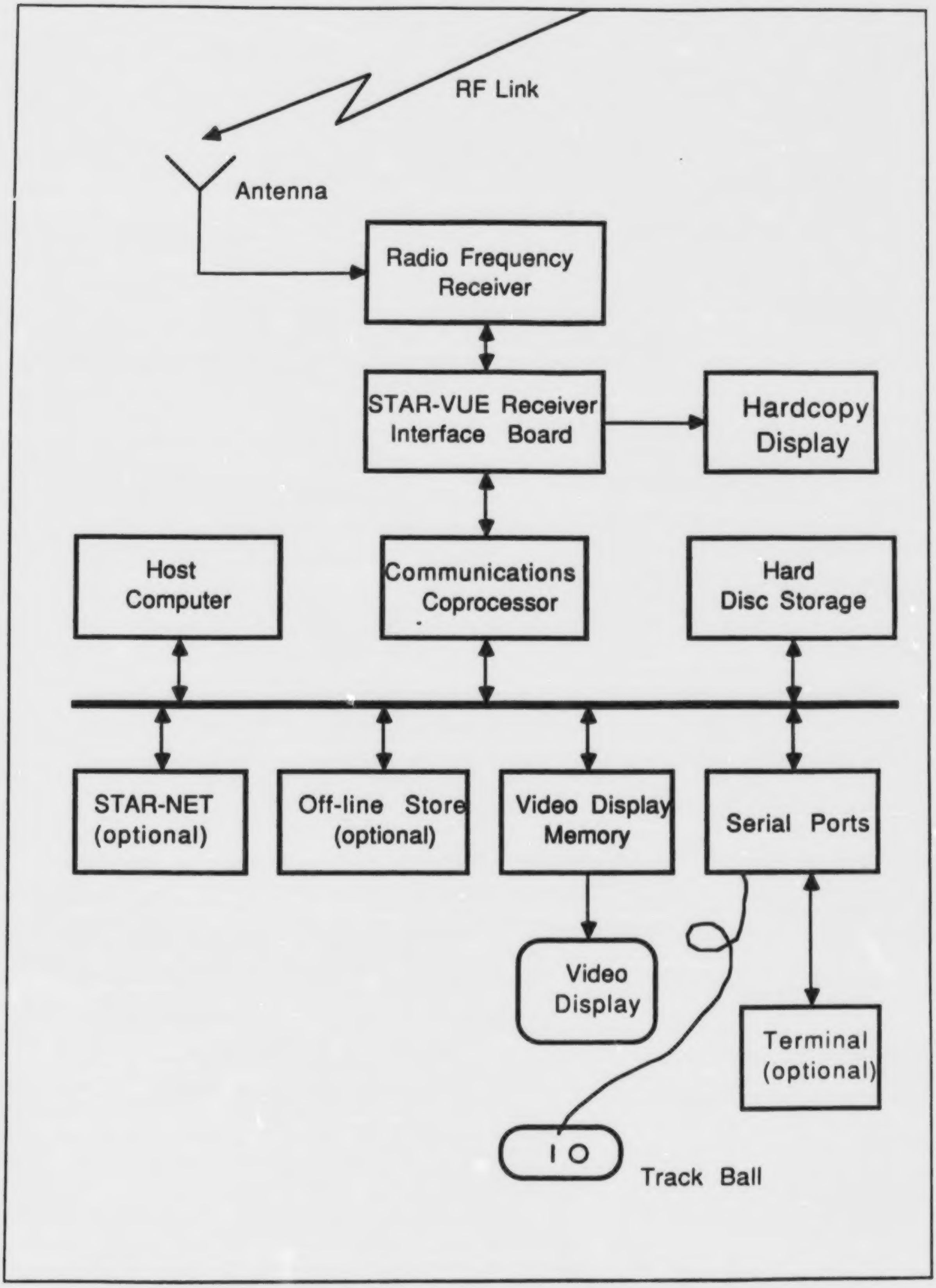

RF Link
Antenna
Radio Frequency Receiver
STAR-VUE Receiver Interface Board
Hardcopy Display
Host Computer
Communications Coprocessor
Hard Disc Storage
STAR-NET (optional)
Off-line Store (optional)
Video Display Memory
Serial Ports
Video Display
Terminal (optional)
I O
Track Ball

Figure 3 Block diagram of STAR-VUE system.

The SRIB descrambles the bit stream, detects the start of line, converts the data to parallel digital stream, and provides an interface for a continuous strip hardcopy display.

The Communications Coprocessor is the prime interface between the software controlled environment and the hardware driven downlink. It has substantial computational power and under some conditions reformats the data before passing them on to the host computer. The system is controlled by a Digital Equipment Corporation mini-computer. The STAR-VUE software is supported by a real-time event-driven operating system. Future developments of higher data rates and more complex software such as AI approaches to ice classification are planned. Therefore, a medium-sized computer at the low end of a product line with clear upgrade paths was desired.

The hard disk is selected from the currently available system which matches the requirements of both the storage capacity and the ruggedness required by the user. Typical disk sizes are from 100 to 500 megabytes. The off-line storage and backup store is typically provided by tape recorders.

3.3.3 The User Interface

The STAR-VUE interface was tailored to a high resolution colour raster display. The graphics controller implements a bus interface, drawing processor, 2048 x 1024 x 8 bit image memory, colour lookup tables, and an RGB output stage. A trackball with three buttons functions as the primary input tool. The x and y outputs of this device control the movement of a small cross or cursor displayed on the screen.

3.3.4 The User's Model

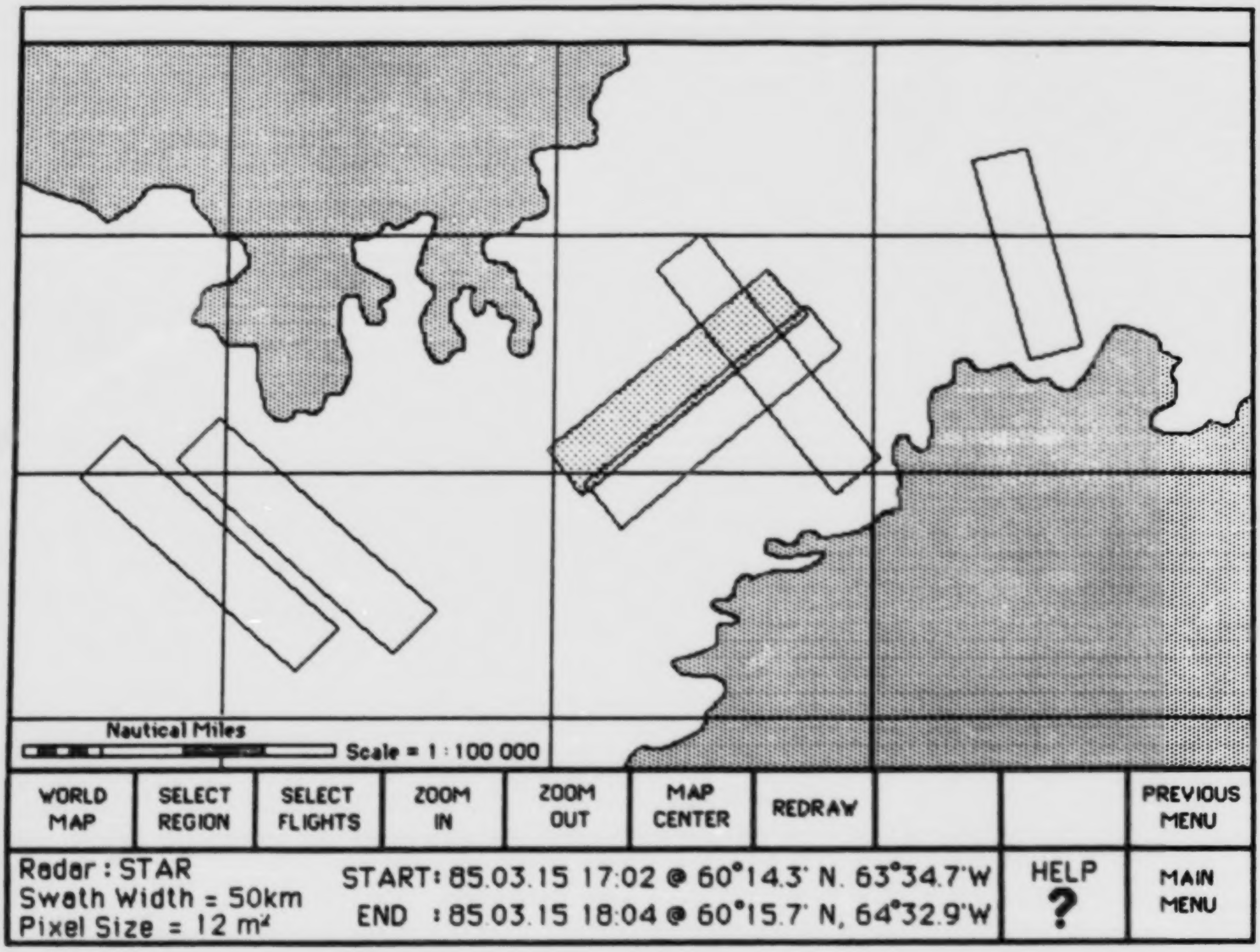
Since the principal activity of the user is the display of SAR data, a convenient method of manipulating this information was needed. Graphical representations of radar flightlines are therefore used. These appear on a digitized map which shows the area imaged by the radar and stored on the system (Figure 4). By positioning a cursor on any of these lines, the radar video is displayed. Thus, the user only has to be concerned with manipulating this convenient conceptual model of flightlines to interact with the system.

3.3.5 Functions

Functions are presented as a series of labelled buttons located along the bottom of the display. A multi-level menu is invoked by positioning the cursor on any of the soft keys. Graphical input techniques are also utilized to allow the user to perform other tasks (Figure 2).

3.3.6 Information Display

Imagery, maps, status and control information are presented to the


Nautical Miles
Scale = 1 : 100 000
WORLD MAP
SELECT REGION
SELECT FLIGHTS
ZOOM IN
ZOOM OUT
MAP CENTER
REDRAW
PREVIOUS MENU
HELP ?
MAIN MENU

Radar : STAR
Swath Width = 50km
Pixel Size = $12\ m^2$

START: 85.03.15 17:02 @ 60°14.3' N, 63°34.7'W
END : 85.03.15 18:04 @ 60°15.7' N, 64°32.9'W

Figure 4 STAR-VUE digital map data base showing graphical icons for flightline which represent data stored on the System.

STAR-VUE operator on a display which is divided into four areas or windows. A status line located at the top of the display gives information on events occurring on the system. Below the status line is the data area, which can be partitioned into several windows displaying different data. The panel of soft buttons for command selection is displayed below this area. Finally, a message area appears at the bottom of the display. This area is used for messages, coaching and to provide other feedback to the user (Figure 2).

3.3.7 Operation

STAR-VUE is operated mainly through the menu of soft buttons. The main functions include:

1. Select Flights. Displays information about the imagery stored by the system. The region of interest can also be specific via a map data base. The user only needs to place the cursor on the flightline of interest to obtain information about the stored imagery, such as swath width, resolution, etc. (Figure 5);

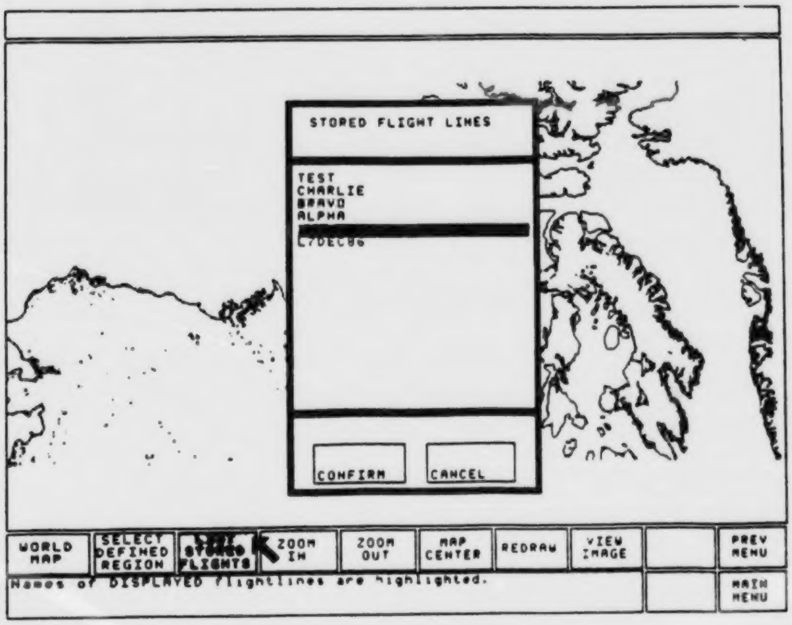
2. View Image. Allows any stored image to be selected and displayed in detail. Two windows are used: an overview window and a detail window. An entire flightline can be scanned at high resolution by moving an adjustable cursor on the overview. The data appearing in the outlined area are then displayed in the detail window. The size of the window cursor can be adjusted such that imagery can be viewed at any desired resolution (Figure 6); and

3. View Reception. Uses the full screen to display incoming downlink data as they are automatically received. The user can work with the data immediately by freezing the display. Data continue to be stored on disk for later viewing (Figure 7).

3.4 STAR-VUE Upgrades

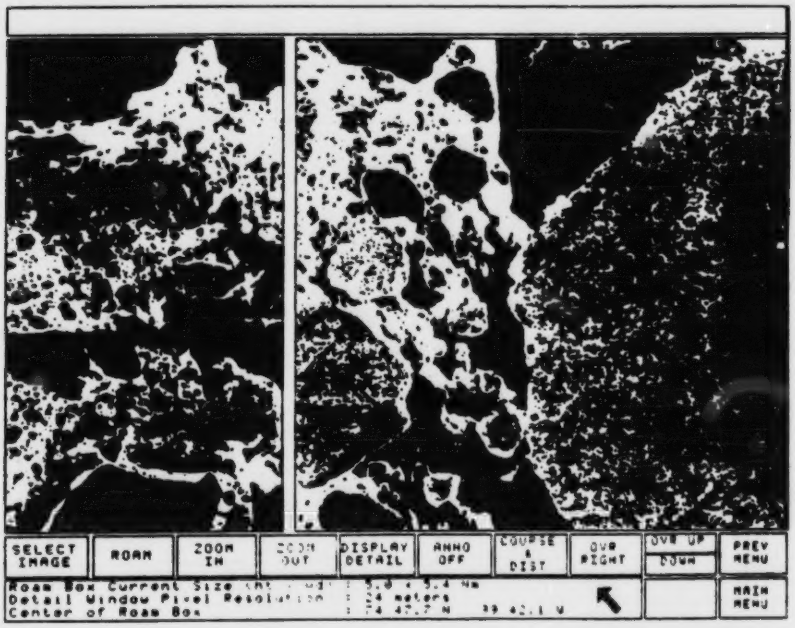
A primary objective of the TDC-sponsored program was to upgrade the STAR-VUE airborne radar display system. Specifically, this work focused on the design, development and testing of new software modules in order to tailor the system for the task of ice navigation.

During the course of this project, TDC had also sponsored an extensive program designed to improve the ergonomics of the STAR-VUE system, i.e., to make the system easier to use by ship's personnel. Many of the design changes recommended by the human factors experts have already been incorporated into the STAR-VUE system. This is the subject of another TDC report. The following is a description of the key STAR-VUE features which have been implemented as part of this program. Because of the complex nature of the software involved, what is reported here is a brief description of the key functions implemented, along with the rationale behind these features. Whenever possible, INTERA has made use of existing software to speed the


STORED FLIGHT LINES
TEST
CHARLIE
BRAVO
ALPHA
27DEC86
CONFIRM
CANCEL
WORLD MAP
SELECT DEFINED REGION
LAST STORED FLIGHTS
ZOOM IN
ZOOM OUT
MAP CENTER
REDRAW
VIEW IMAGE
PREV MENU
MAIN MENU

Names of DISPLAYED flightlines are highlighted.

Figure 5. The STAR-VUE display screen that is invoked via the last stored flights menu. Note information on selected flights appears in the message window at the bottom of the display.


SELECT IMAGE
ROAM
ZOOM IN
ZOOM OUT
DISPLAY DETAIL
ANNO OFF
COURSE & DIST
OVR RIGHT
OVR UP
DOWN
PREV MENU
MAIN MENU

Roam Box Current Size [illegible] : 5.0 x 5.4 Nm
Detail Window Pixel Resolution : 24 meters
Center of Roam Box : 74 47.7 N 39 42.1 W

Figure 6. The STAR-VUE display screen showing imagery that is displayed with the view image function. Both an overview and zoomed in section are present.

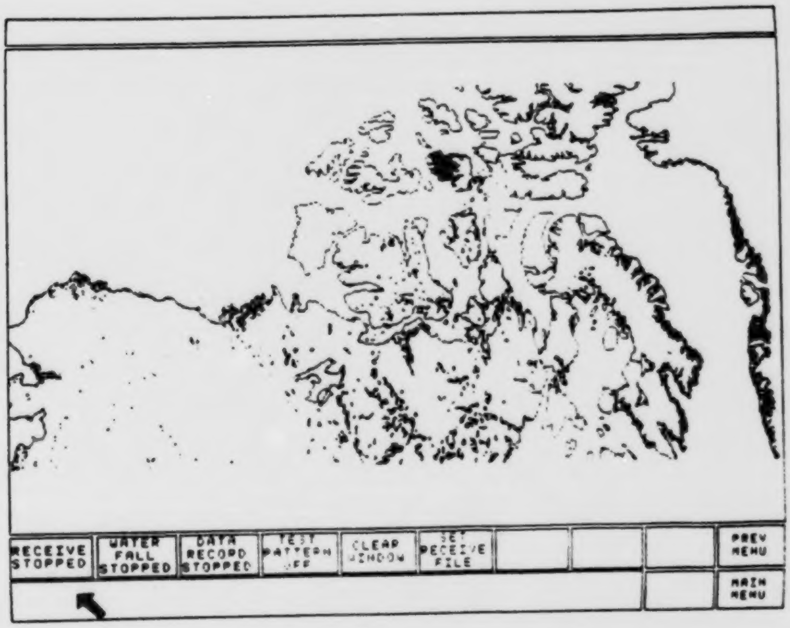

RECEIVE STOPPED
WATER FALL STOPPED
DATA RECORD STOPPED
TEST PATTERN OFF
CLEAR WINDOW
SET RECEIVE FILE
PREV MENU
MAIN MENU

Figure 7. The STAR-VUE display showing the receive data menu. The imagery will be displayed continuously on the screen as it is received in a waterfall fashion.

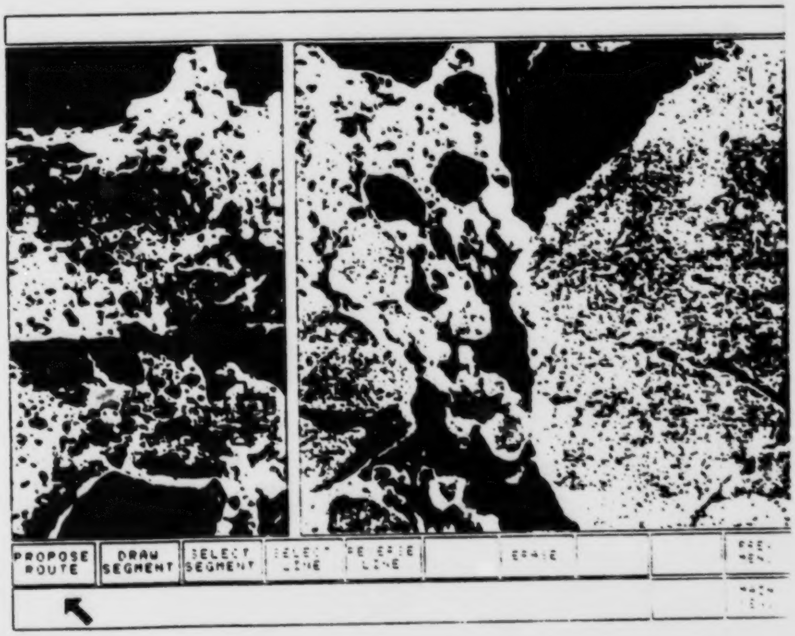

PROPOSE ROUTE
DRAW SEGMENT
SELECT SEGMENT
SELECT LINE
REVERSE LINE
ERASE

Figure 8. Course and distance menu.

implementation and maintain a consistent user interface.

3.4.1 Course and Distance

The most important task for a ship's crew is to view the imagery of the ice in the vicinity of the vessel and along the proposed course. (For stationary drilling platforms, the reverse motion is considered.) The exact location of the ship is assumed known from the ship's systems, and the location of the imagery is obtained from the annotation. However, given the potential errors in position of the plane and ship, combined with the movement of the ice, this is not always adequate to locate the ship. This precision location can generally be done using the marine radar on the ship, displayed on a bright screen. By tracking the ship's location on the display of the SAR data, a record of the ship's passage through the ice is maintained.

The airborne SAR provides the right level of information to be used as an ice navigation chart. In order for navigators to make better use of this chart, however, several features were added to STAR-VUE. A course and distance function has been incorporated into STAR-VUE to plot the ship's course on the imagery and determine the distance to targets. Waypoints can be entered into the system for course planning. Distance to hazardous targets can be estimated for corrective action. Waypoints are plotted in yellow and green, range and bearing in red. Distances are expressed in nautical miles.

Clicking on the Main Menu Button labelled Course and Distance with the trackball presents the menu buttons associated with obtaining range and bearing information and plotting the ship's course directly on the imagery. The button on the far left of the screen can be toggled to plot a proposed course or to plot the actual course taken by the ship. The proposed course is plotted in green, the actual course in yellow.

Draw Segment

When the draw segment is clicked upon, the arrow cursor is replaced by a cross hair cursor, which is placed within the current Detail Window (Figure 8). If no segments have been drawn previously, then the cursor will be initially placed in the center of the Detail Window. If segments have been previously drawn, then the cross hair will be placed at the end of the currently selected segment (usually the last one drawn). This is done in anticipation of the user's desire to plot a contiguous path. The cursor is not pasted down at this point, but rather is attached to the trackball and may be moved with it. The starting point of a line segment is pasted down by clicking on the trackball button after the cross hair has been correctly positioned. The cross hair may now be moved away from this starting point, and as this is done, a "rubber band" line segment is drawn from the starting point to the location of the cross hair. As the cross hair is moved away from the starting point, this line segment stretches, staying connected between the cross hair and the starting point. When the appropriate ending point for the line segment has been reached, the trackball button may be clicked upon and the end point pasted down.

This action causes the path length line segment has been reached, the trackball button may be clicked upon and the end point pasted down. This action causes the path length (range) and bearing information to be given for the line segment, appearing in the Message Window. This line segment now becomes the selected one, being highlighted in red. If DRAW SEGMENT is clicked on again, the cross hair will be placed at the end point of this new segment, to allow the path to be continued if desired. After the end point has been pasted down, any other RANGE & BEARING Menu Button may be clicked upon.

Select Segment

If more than one segment has been drawn in the Detail Window, it would be desirable to select each one in turn so that the range and bearing information on each segment could be obtained, or so that individual line segments could be deleted as desired. This is the function of SELECT SEGMENT. When this button is repeatedly clicked upon, the segment lines are highlighted one by one in the order in which they were drawn. As each one is highlighted, it becomes the selected segment, and range and bearing information appears on it in the Message Window.

Delete Segment

At any time this menu Button may be clicked upon to delete the line segment which has been selected. If a line has just been drawn, and no other operation has been performed, then it is also the "selected" line segment. Thus if it has been incorrectly placed, it may be rapidly removed. Should the operator wish to delete an earlier line segment, it may be selected first via the SELECT SEGMENT Menu Button, and then deleted via the DELETE SEGMENT Menu Button.

Erase Segments

Should the operator no longer need the line segments which have been drawn, then clicking on this menu button erases ALL the line segments from the display and all the range and bearing information stored on them.

Course Planning

By using the select segment function, the proposed ship's course can be plotted on the display with the waypoints selected. This plotting can be done in both the display detail window and the overview window.

STAR-VUE currently uses the algorithm detailed in "Practical Navigation for Second Mates", authored by I.M.O. For course and distance calculations, due to the distances involved, plane sailing calculations are used rather than great circle calculations. This function is shown in Figure 9.

3.4.2 Track Ship's Progress

Besides being able to plot the ship's course through the ice, it is also desirable to track the actual course taken by the ship through the ice. This facility has been built into the STAR-VUE system and is available as a second menu choice called "actual course". This is implemented using the same draw segment functions but with a different graphical overlay in a different colour. The planned course is shown in green while the ship's progress is marked in yellow. The erase function is shown in Figure 9 where all segments belonging to the current route are removed from the display.

By using the above two functions, navigators can now plot waypoints and keep track of the actual course taken by the ship on the ice imagery, thus optimizing the ship's transit through the ice.

Time to Targets

At one time, it was thought that it may be useful to determine the travel time to waypoints based on the ship's speed. Further discussions with the personnel on the M.V. Arctic, however, revealed that such a function would probably not be used very frequently. The ship's speed in ice is not very accurate when obtained directly from the ship's doppler log because of the ice. The time to targets function was therefore not implemented. As the navigation systems used on ships improve and GPS becomes standard, positional information from the ship's nav system could be transferred directly to STAR-VUE and the position of the ship shown on the display. This would be a much more useful function and should be considered as a future development.

3.4.3 Map Data Base

Since the principal activity of the user is the display of SAR data, a convenient method of manipulating this information was needed. Graphical representations of radar flight lines were therefore used. These appear on a digitized map which shows the area imaged by the radar and stored on the system.

When the IMAGE INFO button is pressed, the contents of the active area of the main display are cleared and then replaced by a map window. Within this window a map will appear, showing the location of flightlines which cover areas within the region (Figure 10). The operator may then move the cursor to a specific image line and click upon the trackball. Information will be placed in the message area of the display indicating the date/time of coverage (start and end of flight), position information (likely latitude and longitude), resolution of data set (size of pixels) and type of imaging system used to collect the data. The selected flightline will be the one of current interest, and will be highlighted on the display.

The panel of buttons will contain the Standard Buttons (PREVIOUS MENU, MAIN MENU, HELP and OTHER OPTIONS if appropriate), as well as the following:

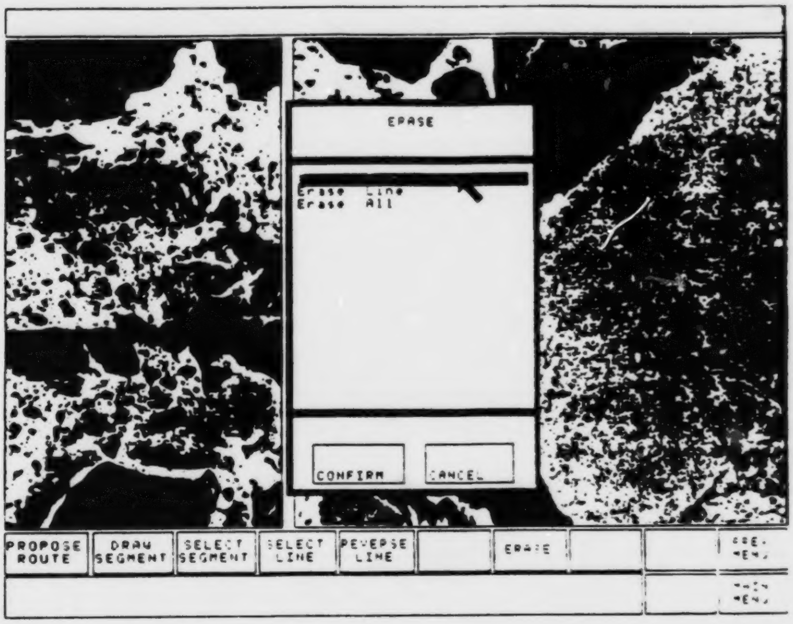

ERASE
Erase Line
Erase All
CONFIRM
CANCEL
PROPOSE ROUTE
DRAW SEGMENT
SELECT SEGMENT
SELECT LINE
REVERSE LINE
ERASE
PREV MENU
MAIN MENU

Figure 9. The erase function.

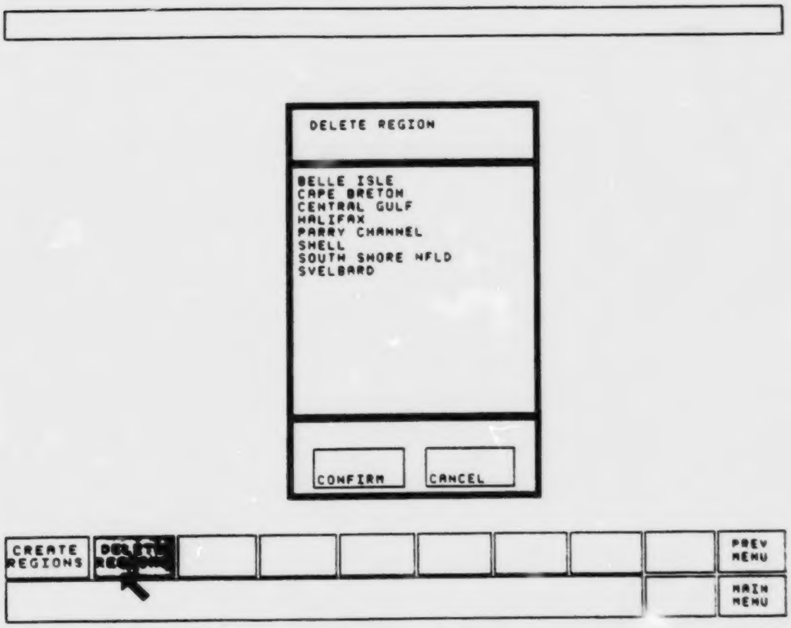

DELETE REGION
BELLE ISLE
CAPE BRETON
CENTRAL GULF
HALIFAX
PARRY CHANNEL
SHELL
SOUTH SHORE NFLD
SVELBARD
CONFIRM
CANCEL
CREATE REGIONS
DELETE REGIONS
PREV MENU
MAIN MENU

Figure 10. Map data base function showing the utilities to delete a map displayed on the system.

WORLD MAP: This button presents a map of the "world" which has been defined, likely an area covering all of the Northern Hemisphere regions where STAR-VUE would be operating.

SELECT FLIGHTS: The SELECT FLIGHTS button provides the ability to remove or include flightlines from being displayed on the map. The primary purpose of this button is to allow stratification of specific lines based upon time.

ZOOM IN: As the name suggests, the ZOOM IN button is used to alter the scale of displayed maps. By pressing this button, the scale at which maps will be drawn is increased. This scale change will take effect the next time the REDRAW button is pressed.

ZOOM OUT: ZOOM OUT performs the opposite function from ZOOM IN. When pressed, the scale at which maps will be drawn is increased.

MAP CENTER: The MAP CENTER button (Figure 11) allows the operator to make adjustments in the location of the map being displayed. By pressing this button, a new map center may be indicated to STAR-VUE. The map can then be redrawn on the display with this new center point.

REDRAW: The REDRAW button is used to request STAR-VUE to redraw the displayed map based upon the current scale and location parameters.

One of the major problems with the use of the world map function is that it takes a long time for the computer to redraw the map at different scales. This is primarily because the map data base is fairly extensive since it must contain all the information required to draw a map at any desired resolution.

In order to improve the speed of the draw function, a facility was added to allow users to store the map displayed at a chosen resolution for quick recall. By pressing the SELECT REGION button, the operator can choose amongst a number of his defined geographical regions. When a region is selected, the map of that region will be displayed.

The SELECT REGION button will cause a pop-up dialogue box to appear on the display screen, as shown in Figure 11. Within the box will appear a list of defined geographical areas, with the current area highlighted. If the desired region is not visible on the pop-up menu window, and if there are more selections available but not displayed, then clicking on the SCROLL UP and SCROLL DOWN button at the top and bottom of the menu list will display them. By moving the cursor up to an entry in the list and clicking on the trackball, the user can obtain information about the desired geographical area. The selected area tentatively becomes the next choice for map display. If the user wishes to confirm this choice, the cursor should be moved to the CONFIRM button displayed in the dialogue box and click on the trackball. This will cause the pop-up box to disappear, and the selected map region to be drawn on the display. If the user does not wish to change the currently displayed map, then rolling to the CANCEL button and clicking on the trackball will cause the pop-up box to disappear without changing the map. Alternatively, if the operator was to move the cursor to a button on the main panel, or into the map area and click on the trackball, the pop-up box will be cancelled without any change to the display.

3.4.4 VIEW IMAGE

Once an image line has been received, the user will likely want to examine it in detail; this is accomplished via the VIEW IMAGE screen. Initially, this screen will contain two or more windows and the menu choices described below. After initial power up of the system, all of the windows will be empty of imagery. The leftmost of these windows is called the Overview Window, which, when loaded, will contain a compressed resolution representation of a section of a flightline. The other window(s) are called Detail Windows, which will contain high resolution images extracted from one (or more) flightline(s). The Message Window at the bottom of the screen will provide guidance information, detailed information and error messages to the operator. The Status Line(s) will display information on the general status of STAR-VUE as it does on all other screens. The choices in the VIEW IMAGE menu allow a detailed examination of any portion of any received image. This menu presents the standard buttons (PREVIOUS MENU, MAIN MENU, HELP and OTHER OPTIONS), as well as the following ones:

SELECT IMAGE: Allows the selection of an image line so that it may be looked at in more detail. Selection is done via a screen similar to the one presented for IMAGE INFO.

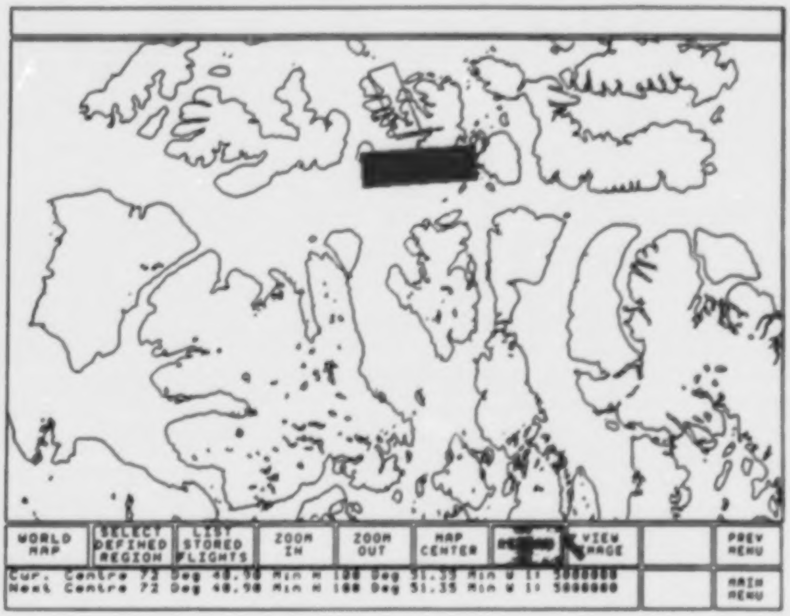
ROAM: This button allows the selection of a portion of the Overview Window to be displayed in a Detail Window.

ZOOM IN/ZOOM OUT: These two menu buttons change the size of the selection box used by ROAM. This allows the Detail Windows to show portions of the Overview Window at different levels of magnification.

DISPLAY DETAIL: This menu button places the contents of the ROAM box in the Detail Window, once the proper location and zoom level have been selected.

ANNO ON/OFF: The ANNO ON/OFF button is used to toggle the display of annotation on the windows. The nature of the annotation will be presented later.

One of the major problems with the view image function when it was first implemented was that the response time of the display detail image was rather slow. This situation has been improved under this program by incorporating some new software and hardware changes. In addition, a new menu (Figure 12) has been added to VIEW IMAGE called


WORLD MAP
SELECT DEFINED REGION
LIST STORED FLIGHTS
ZOOM IN
ZOOM OUT
MAP CENTER
VIEW IMAGE
PREV MENU
MAIN MENU

```
Cur.  Centre 72 Deg 48.90 Min N 100 Deg 51.35 Min W 1: 5000000
Next  Centre 72 Deg 48.90 Min N 100 Deg 51.35 Min W 1: 5000000
```

Figure 11. The result of map re-centering.

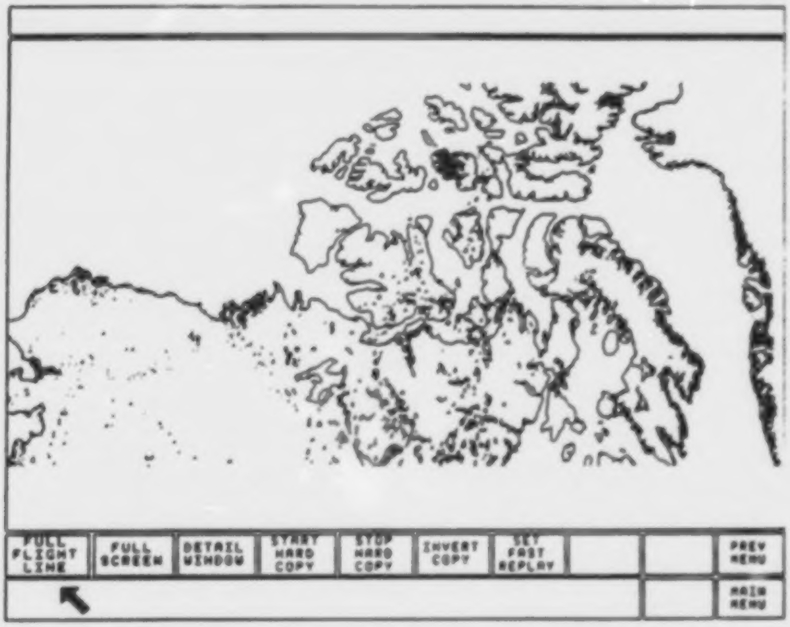

FULL FLIGHT LINE
FULL SCREEN
DETAIL WINDOW
START HARD COPY
STOP HARD COPY
INVERT COPY
SET FAST REPLAY
PREV MENU
MAIN MENU

Figure 12. Print menu function used for EDU printer.

print. When the print button is pressed, another menu is displayed. This menu allows the printing of the Overview Window, Display Detail Window and/or the entire flightline. The current hardcopy display device used for printing is the EDO Western Film Recorder. The driver for the EDO Recorder is located in the STAR-VUE receiver board, which allows data to be received or played out of the system.

3.4.5 Annotation

During the shipboard testing of the STAR-VUE system, it became obvious that some form of geographic annotation was needed on the imagery in order to establish position and to route the vessel. Because INTERA's STAR-1 SAR was an unannotated radar at the time of this project, the positional information of the aircraft (hence the flightlines) had to be passed by radio to the ship. Once these coordinates for the flightlines were received, they had to be entered into the STAR-VUE system. A menu was established for this purpose during this project. Once coordinates were entered into the system, directional information could be obtained from the imagery. Pressing the annotation button caused a north arrow to be displayed on the image. Positional information for any point on the image could be obtained by placing the draw segment cursor on any point of the image . Course and distance information was also readily available from this same menu.

3.5 Shipboard Trials

During the course of this program, several of the functions which were developed were field-tested on the M.V. Arctic. The hardware system (Figure 13) for shipboard use consisted of:

219.5 MHz FM Receiver
INTERA Receiver and Hardcopy Interface Boards
PDP11/73 C/W 2Mb Memory, Expansion Box
Priam 235 Mb (Winchester) Disk
Keyboard, VDU
Parallax Graphics Board
Hitachi 2719 High Resolution Display
Trackball
STAR-VUE Software, Current at Time of Delivery

3.5.1 STAR-VUE Trials

Since STAR-VUE had never operated onboard a ship, there was some concern that the equipment would not tolerate the mechanical and electrical environment.

The major part of trials was to verify the operation of STAR-VUE and to get a better understanding of how airborne radar (SAR) is used for navigation in ice.

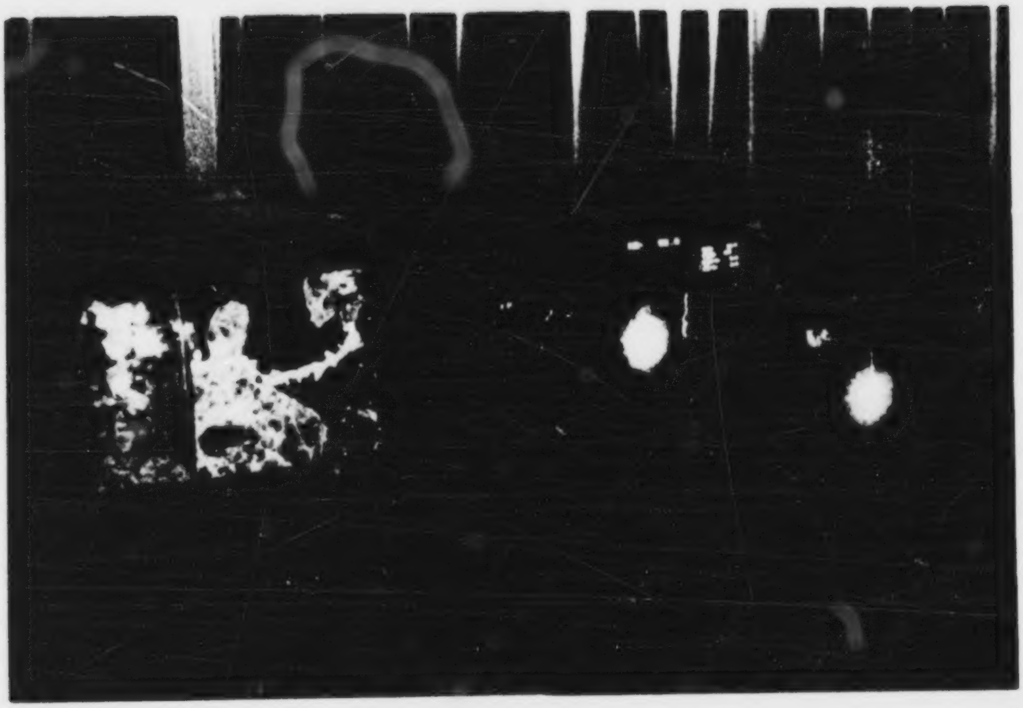


Figure 13. STAR-VUE/MARINE-VUE hardware installed on M.V. Arctic.

Another function of the trials was to verify that the new choice of receiver and receiver interface was going to give satisfactory results.

Last, but by no means least, the ship's officers should be encouraged to use the system and provide as much feedback as possible.

The following is a brief description of the shipboard testing that was undertaken for the STAR-VUE system.

The signals were received on a vertical dipole antenna cut for optimum response on 219.5 MHz. It was manufactured by Sinclair Radio Laboratories under the model number SRL225. The output of the antenna was fed to a pre-amplifier mounted nearby. The pre-amplifier was on loan from INTERA Technologies and offers high gain and low noise performance. Its disadvantage for this particular application was that a separate power cable had to be run up the mast carrying 110 VAC. The amplified signal was fed via RG-8 cable to the bridge of the M.V. Arctic.

To aid with the system comparisons (i.e., STAR-VUE and "old" 256 kb/s downlink), a precision signal divider was used to share the signal between the two systems. One of the outputs fed the existing Microdyne Receiver and the other went to the Emhiser receiver.

The Emhiser receiver is manufactured to military standards in a small package; it is only suitable for operation on one frequency, 219.5 MHz in this case.

The demodulated signal is then fed to the receiver interface via the hardcopy interface. The hardcopy interface also contains a test pattern generator which can be enabled (by software or hardware) in place of the signal from the receiver.

The receiver interface performs a number of functions:

- o Recovery of data and clock from the receiver data.
- o Detection of start of line code.
- o Division of serial data into 2048 or 4096 pixel lines.
- o Buffering to output data to the co-processor (KXT11-CA).
- o Decoding of control commands from the co-processor.
- o Delivery of either realtime or disk file data to the hardcopy board for display on an image recorder.

The real-time received data are transferred to the co-processor (which can perform line averaging, if required), and then to the PRIAM 235 Mbyte computer disk.

Control of the STAR-VUE menu system is affected by a Disk Instruments LX-200 trackball. Graphics are generated by a two-board set manufactured by Parallax (600 Q-8-EM), which transmits video signals to the monitor in the RS-170 format (RGB plus sync). The video signals are displayed using a high resolution colour monitor, Hitachi model 2719.

A Wyse WY-75 terminal was used to perform operator dialogue functions not incorporated in the STAR-VUE menu system.

Output to a hardcopy device, either in realtime or via playback from disk file, is carried out by the hardcopy interface. The analogue outputs from this VIDEO, TRIGGER and VALID are specifically designed for use with an EDO Western 590 Image Recorder.

Mobilization

The STAR-VUE system was initially taken to Canarctic's premises in Ottawa for 1-2 May 1986. This was to provide familiarization to the ship's officers and also for them to partake in an "Ergonometric evaluation of STAR-VUE and NAV-ICE" under the direction of Dr. J. Ells from the University of Calgary.

The equipment was subsequently installed on M.V. Arctic and brought to an operational status. Final testing involved flying INTERA's SLAR aircraft over Port Weller while downlinking real-time SLAR, playback SLAR or test-pattern. The limited range exhibited during this testing led to re-cabling of the antenna to ship's bridge run and the addition of a mast-head pre-amplifier.

3.5.2 First Voyage - May 1986

The PRIAM disk drive appeared to fail soon after departure from the Gulf of St. Lawrence. It was feared that the mechanical environment had been too much for it and head disk contact had occurred.

Sufficient storage was available to allow acquisition of downlinked data from INTERA's SLAR flights of 31 May and 1 June. Good ranges were obtained from the STAR-VUE downlink and in fact, performance at maximum range was reported to be superior to that of the "old" 256 kb/s downlink. Since the signals from the pre-amplifier were split equally between STAR-VUE and the "old" downlink, these results indicated that the Emhiser receiver and the bit synchronizer incorporated in the STAR-VUE Receiver Interface were functioning just as well if not better than the Microdyne receiver and stand-alone bit synchronizer. Prior to these tests, there was some concern that this hardware combination would give satisfactory results.

A proper evaluation of STAR-VUE, however, was not possible due to malfunction of the disk drive and the lack of availability of INTERA's STAR-1 aircraft.

The "defective" disk was returned to PRIAM. They found the following:

a) No damage done to the disk surface;
b) A switch was incorrectly set, so as to restrict access to

the whole of the disk; and

c) The unit was unable to meet temperature cycling specifications.

PRIAM changed the Head Disk Assembly installed in the disk drive and the system performed to specification.

Shock/vibration mounts were fitted to the disk drive when it was returned to Calgary. It was then shipped to Nordenham, Germany, for re-installation. The system was left in a diagnostic mode for the crossing. On arrival in the Canadian Arctic, the error log was checked and found to contain insignificant errors through disk malfunction.

3.5.3 Second Voyage - August 1986

Since the first voyage, the receiver interface and hardcopy interface had been replaced by production boards, the originals being Miller Communication Systems prototypes. The first downlink from STAR-1 produced some strange degradation of the received image. The problem was later found to be in the production receiver interface: due to a schematic error, a pin on a chip that should have been grounded was in fact left floating high. The effect of this error was that every set of 16 pixels was displayed in reverse sequence. The correction to the hardware was tested on INTERA's STAR-VUE system at Tuk base and was passed on to M.V. Arctic for implementation.

3.5.4 29 October - 10 November Voyage

INTERA personnel brought equipment to perform a thorough check of the radio frequency segment of the STAR-VUE downlink.

A Wavtek 3000 VHF signal generator and an HP power meter were used to check the performance of the pre-amplifier and downlead. Both were found to be in good order:

Pre-amp gain = 29dB
Loss in coaxial cable = 4dB
Overall gain in pre-amp and coaxial cable = 24dB

The splitter was also found to be working correctly. A check on the Microdyne receiver sensitivity revealed an irregular performance of the signal strength meter. The meter needle increased in deflection until it reached 3.5 divisions at an input signal strength of -65dbm, a typical signal at the receiver input. Further increases in signal had no effect on the signal strength reading. The Wavtek 3000 was not capable of handling the 256 kb/s modulation used by the downlink, so it was not possible to perform a full digital transmission test.

All checks done on the STAR-VUE system indicated everything was in order.

STAR-1 data were successfully downlinked to STAR-VUE system on 29 October. It was apparent that the STAR-VUE was managing better in the extreme range signal conditions than the "old" downlink. Ranges of 180 nm were achieved with both downlinks.

This was the first use of STAR-VUE with fully functional hardware. With the hardware problems resolved, it was now possible to examine the operation of the software.

Some serious difficulties came to light, principally the two-mode operation of the STAR-VUE and also the delays experienced in making the data available for display. Occasionally the system would lock out completely while swapping from STAR-VUE mode to acquisition mode. This could sometimes only be resolved by powering down and powering up the expansion box.

The system existing on 29 October 1986 had the STAR-VUE interactive display software completely separate from the receiver subsystem. Data could be displayed using the STAR-VUE menu system but when it came to acquiring data, it was necessary to shut down the STAR-VUE software (by issuing @ ENDVUE) and loading the receiver system. The receiver subsystem was capable of recording the data to disk and displaying the realtime data in "waterfall" mode, but a view of the current or any other imagery was not possible at the same time. Furthermore, when a sequence of lines was being acquired, there was usually very little time between lines to view data. Another delay was experienced in developing the overview file; this is the image which resides on the smaller panel on the left side of the screen. The overview file was generated from raw data file (full data set, as downlinked) after the raw data file was closed. The data were simply averaged but the time taken for a typical flight line was 30 minutes plus.

Problems were encountered with the storage of data. Files for raw data had to be pre-allocated. If sufficient room was not allocated, the surplus data would simply be lost without any warning. Usually the length of the line was known beforehand, but problems would occur if the aircraft flew lines in a different sequence to that already planned. STAR-VUE would have been acquiring data for some time before it became clear which line was being recorded.

It was not possible to view any incoming data on the "waterfall" display without recording data to disk file. This meant that not only were the raw data cluttered up with noise and test pattern, but also the first recorded line of noise was registered against the start of line coordinates. Similar problems occurred when part of a flightline was out of downlink range, as the software would assign the first data received to the start of the line coordinates and the last data received to the end of line coordinates. This meant that any geographic coordinates picked from the imagery will be erroneous unless special efforts are made to correct the flightline coordinates to those corresponding to the coverage actually received.

While operating in STAR-VUE mode (displaying imagery), the selection of a required section of imagery was found clumsy. If a different section of the line was required, the system would take considerable time redrawing the "world map" before allowing the operator to pick a new part of the flightline. The new pick would have to be displayed in the overview box before the operator could confirm he had the correct piece of imagery. If it was not what he wanted, the process would have to be repeated.

The STAR-VUE system clearly offered a better tonal range than the previous dry silver product. Users found it difficult to adapt the positive image being displayed as they were accustomed to seeing negative imagery on dry silver.

A more fundamental problem became apparent with softcopy as opposed to the hardcopy previously supplied. The hardcopy was very easy to orientate and neighbouring flightlines could easily be overlapped to gain a general overview of the situation. STAR-VUE did not allow anything similar to this. Imagery was presented with the line orientation to the top of the screen and it was not possible to view more than one line simultaneously.

There seemed to be a general problem in tracking the ship from one set of imagery to another. When tracking the ship's location using the COURSE and DISTANCE function, the coordinates for the lines seemed to be available only for the line on which they were originally plotted. When switching to an image that overlapped the existing track, there would be no record of the previous path followed by the ship. It would certainly be very valuable to be able to go from one set of imagery to a second with some idea of where the ship might be on the second image. It has been noticed that when ice floes were similar in size and form, and conditions were dynamic, it was very easy to get lost while going from one set of imagery to the next.

3.5.5 Winter Probe Voyage - November/December 1986

One significant upgrade made to the STAR-VUE system was the addition of a data averager. The generation of the overview file in the system had been painfully slow. The new averager ran at least twice the previous speed.

The graphic presentation of the imagery was changed to the "inverted" or negative state to give imagery which looked similar to that of dry silver.

The "nautical" modifications described earlier were also included. The roam box dimensions were now reported in nautical miles instead of kilometers. "Range and bearing" labelling was changed to "course and distance". New hardware and software were also included to try the first integration of MARINE-VUE with STAR-VUE. A single asynchronous interface (DLVEI-M) was introduced into the STAR-VUE expansion box in order for STAR-VUE to communicate with the Folsom box. A new set of menus were available on the STAR-VUE which effectively duplicated the controls on the front panel of the Folsom box. It had been hoped that new PROM's would have been available for the Folsom box which would have given it some of the features already found to be lacking. Unfortunately, the PROMs did not turn up in time for this voyage.

The Winter Probe was unfortunately called off on 3 December after a reconnaissance STAR-1 flight indicated that conditions were not favourable.

3.5.6 Achievements

Hardware problems dominated in the early part of the year. The poor performance of the r.f. section of the downlink was discovered and rectified before the vessel left Montreal. New cabling and the introduction of a pre-amp resolved the difficulties.

Problems with the PRIAM disk drive were initially thought to be very serious. It was feared that the drive and, for that matter, most drives in the commercial market, would not be robust enough to cope with the environment. The answer then would have been to utilize specially ruggedized drives starting at four times the price of the PRIAM unit. We were relieved to find that our problems were probably caused by an incorrect switch setting. Shock/vibration mounting was well worthwhile and should extend the life of the drive.

Some problems then surfaced with the production models of the receiver interface boards. With these resolved, no further hardware performance or reliability problems were experienced in the 1986 program.

It was shown that the Emhiser receiver and built-in Bit Synchronizer performed quite adequately. In fact, results at extreme range were distinctly better than those achieved by the "old" 256 kb/s downlink.

Concerning the software, all of the major problems have now been resolved. The software implemented as part of the TDC program described earlier was installed on the shipboard system. Regrettably, many of these modules were installed too late for testing on Canarctic's system in the 1986 season.

The selection of a portion of a line has been made easier by having the overview window scroll up and down; there is no longer a need to return to the world map. Modifications were made to present the overview and detailed imagery within 90° of north up. An arrow was added to indicate direction north on the imagery.

A modification was made to the look-up tables in the graphics software so as to output negative imagery to the screen, as requested by Canarctic.

A new averaging system was installed during the Winter Probe. This reduced the delay in generating the overview file and made the data available for viewing more quickly. Any delay is clearly unsatisfactory, therefore more thought needs to be applied to this problem.

3.5.7 Conclusions and Recommendations - STAR-VUE

STAR-VUE is now an operational system; most of the initial problems have been resolved. However, some problems remain.

The averaging process to generate the overview file has been accelerated but it is unreasonable to allow any delay in viewing the latest imagery. Current STAR-VUE software has the overview file generated by decimation. While this does allow immediate access to detailed imagery, the decimated overview is not of acceptable quality. Operators prefer to delete the decimated overview image and generate an averaged one. Ideally, the averaged overview should be generated in real time. If this is not possible, the decimated image should be replaced gradually by averaged data in a manner that is transparent to the user.

Some improvements on the entry of flightline coordinates into the system are being made. In the future, such information will be entered via trackball and menu. However, geo-referencing of the imagery will still remain a chore due to either only part of the line being received or a different line than expected being downlinked. Ultimately the only answer is the utilization of the annotation block currently being transmitted by both STAR-1 and STAR-2. This will take a major development effort and will not soon be available. As an interim method of aiding geo-referencing, it would be useful to be able to assign coordinates to recognizable landmarks on the imagery.

On the other hand, an ice navigator in the first instance is interested in where he is with respect to features on the surrounding ice, in which case real-world coordinates may cause confusion.

There is a strong demand from navigating officers for ready access to conventional navigational features, and in particular, to latitude and longitude. This information will be supplied but must be applied with caution and knowledge of the type of error involved. With this proviso in mind, the following features are required:

- o Simpler access to latitude, longitude.
- o Ability to enter a bias to latitude, longitude. (Equivalent to establishing geo-referencing by means of a landmark.)
- o Ability to draw radar fixes on STAR-VUE.
- o "Course made good" to be made available on all flightlines (not just the one it was plotted on).

Concerning the last point, difficulties arise when transferring from one set of imagery to the next. There may be an overlap zone but if much of the ice is the same form and has moved or rotated since the previous image, it may be difficult to quickly figure out the position on the new image.

When plotting actual positions (course made good) on the STAR-VUE screen, the position should be tagged with the time and an optional short comment. As a further aid to keeping track of position, a dead-reckoned position could be derived. A circle drawn with radius proportional to time since last fix should indicate the area to look for the next confirmation of position.

One driving reason behind the development of STAR-VUE's "softcopy" approach was getting rid of the operational problems of hardcopy. From our experience in the 1986 program, hardcopy will not disappear immediately.

There are some strengths in the hardcopy approach which are difficult to replicate in the softcopy presentation:

- The imagery may be rotated to any convenient orientation;
- Easier to gain a general understanding of the situation; and
- Crude mosaicing can be accomplished by putting one image on top of another.

The need for a mosaicing function on the STAR-VUE system is thus very important if the system is to replace the hardcopy facility altogether. This is the subject of the next chapter of this report.

4. MOSAICING STUDY

The purpose of this study was to investigate the question of how airborne radar data can be put together into mosaics using a STAR-VUE or similar facility. The study addresses why mosaicing is required and the problems that have to be overcome in producing mosaics, and recommends procedures and functions which would be required on STAR-VUE to implement the mosaicing. Although there are other applications which require mosaicing of radar data, such as land mapping, this study has focused on the needs of ice navigation and ice management.

Mosaicing is defined and its usefulness is discussed in Section 4.2. The alternatives of mosaicing with hardcopy or softcopy are presented in Section 4.3. (Implementation of mosaicing on existing image display systems is discussed in Section 4.4.) Mosaicing requirements and standards, and implementation of mosaicing on existing image display systems, are discussed in Section 4.5. Finally, a plan for implementing a mosaicing system on STAR-VUE is presented in Section 4.6.

4.1 Defining Mosaicing

WHAT IS MOSAICING?

Mosaicing is the assembly of a set of discrete images into one composite image. Mosaicing is necessary whenever the region of interest must be viewed as a single image but cannot be imaged in one frame. For instance, airborne radar image strips are in the order of 50 km wide with lengths of hundredths of kilometres constrained only by aircraft range. There are two types of registration: geo-registration and image-to-image registration. Geo-registered is the referencing of selected points on the imagery with the known coordinates of control points. The registration accuracy depends on the number of control points, their positional accuracy and the sophistication of the algorithm used to register the imagery. With respect to ice management, geo-registration is accomplished by registering the imagery to landmarks, or stationary vessels. Image-to-image registration is accomplished by referencing identified features in the common overlap area of separate strips of imagery. A mosaic can be generated by either of the aforementioned registration processes or a combination of these processes.

WHY IS A MOSAIC REQUIRED?

There are three primary reasons why individual images need to be mosaiced. First, it is necessary to have some continuity when the vessel transits between images, especially when there is a hazardous feature on the adjacent image. Second, in cases where adequate ground control is lacking on individual images for geo-registration, image-to-image registration may be the only means of improving the locational accuracy of an image. Third, the ice characterization can be improved where local interpretation benefits from local ground truthing.

HOW IS MOSAICED IMAGE USED?

The imagery data required for ice management can be divided into three categories which reflect why a mosaic is required and how a mosaic is utilized. The three categories are:

1. Strategic;
2. Tactical; and
3. Local.

Strategic

In a strategic mode, the focus is on a regional (100 to 200 nautical miles) view of the ice conditions. The type of strategic analysis varies with the user. For instance, vessels focus on identifying different ice types and designing their routes to minimize transit time, fuel burn and to reduce potential hull damage. On the other hand, drilling rigs located at fixed locations wish to know of hazardous features such as the harder/stronger multi-year floes, which may eventually move into their drilling operation area.

In the strategic mode, since decisions impact operations for days, it is necessary to see in one overall picture the ice conditions the user will experience within the next few days. On a strategic scale, there is less need to define details such as ridge systems or individual floes since these can be avoided using smart ice navigation systems (e.g., NAV-ICE). Other factors such as areas of converging or diverging ice which can be inferred from the imagery are of significant benefit.

Tactical

In a tactical mode, the focus is on ice conditions which will be encountered in a time period of a few hours. The area of interest is typically 10 to 20 nautical miles ahead. For a stationary target such as a rig, the time period is a function of the ice velocity, whereas for a vessel the time period is a function of both the ice velocity and the vessel velocity.

In the tactical mode, the need for mosaicing is restricted to cases where the area of interest falls on the edge of two strips of imagery. On a tactical scale, only two adjacent strips of imagery need to be addressed at a time.

In a tactical mode, vessels can employ marine radar to reference their position on the SAR image. Thus, the vessel is able to avoid hazardous ice such as multi-year floes which can be interpreted on the SAR image but not on the marine radar. The task of identifying vessel position on the SAR image becomes more difficult as ice dynamics distort the floes and other distinct features. In order to improve the reliability of locating vessel position when transitting between images, it is necessary to have continuity provided by image-to-image registration.

Local

In a local mode, the focus is on the avoidance of hazardous ice features within the immediate vicinity of the user. These are features which, for instance, the vessel can avoid immediately by turning or stopping.

In a local mode the user makes use of the fullest resolution data available. Since the area of examination is so small, there is no need for a mosaic on the local scale. However, image-to-image registration is critical to allow transition between images.

4.2 MOSAICING ALTERNATIVES

The two alternative approaches to mosaicing that will be discussed in this section are analogue and digital. Analogue means manipulation of the imagery in hardcopy form and digital refers to manipulation of the digital data in softcopy form. The advantages and disadvantages of each approach are discussed in the following sections.

4.2.1 Analogue Mosaicing

The analogue mosaicing procedure is based on the reproduction of individual pieces of imagery on a hardcopy media, typically either film transparencies or photographic prints. The individual pieces are then assembled by a combination of geo-registration to overlay maps and image-to-image registration. In field situations where time is critical, mosaicing requires a combination of cut/paste and stretch/compression techniques. The stretch and compression are limited to the along-track direction and are performed by varying the replay speed of the film drive on the hardcopy reproduction unit. This can be quite time-consuming, since the strips are usually replayed two to three times to achieve the correct along track scale. The across-track scale is usually calibrated in the equipment installation and not adjusted in an operation scenario.

In most ice management situations, the imagery would be geo-registered to known control points such as coastline. In the flight planning process, special attention is made to include some coastline in at least one strip to provide both along track scale and orientation.

Imagery which does not include coastline would then be matched to these registered lines using features in the areas of overlap. If no overlap is available, aircraft positions would be used to position different strips of imagery, keeping in mind the inherent uncertainty of aircraft location. In some cases where no overlap is available, image strips can be positioned by extrapolation of features. The matching is typically done by eye, and because time is usually important, mismatch errors of several kilometers are tolerated.

The requirements for analogue mosaicing include a playback system and hardcopy recorder, production facility (i.e., darkroom and chemicals if film products are used), sufficient space (light table for transparent film) to lay out the mosaics and transparent overlay maps at appropriate scale for geo-referencing imagery. It has been observed that production of transparent overlay maps can be very time-consuming and expensive.

The analogue approach results in a product at one scale and resolution. Changing the scale would require additional software/hardware and going through the same production sequence again. Given imagery of one scale and resolution, the human interpreter makes the transition from local to regional mode by changing the field of view. At the high resolution end, the user is limited by the resolution of the hardcopy media and at the low resolution end by how far back the interpreter can stand from the mosaic.

Analogue mosaicing of SAR imagery has been used very successfully to support drilling and moving vessel operations. It is especially well-suited to a drilling operation such as that which has run in the Beaufort Sea, where many copies of a given mosaic are produced at a shore base at a scale of 1:250,000 and then distributed to many different user types, from management in the main office to supply boat captains. This technique has two drawbacks. First, the personnel and equipment performing the mosaicing are highly trained and sophisticated respectively. Second, there can be a substantial amount of time between data acquisition and final distribution to users.

4.2.2 Digital Mosaicing

Another approach to mosaicing data is to manipulate the data digitally. This, of course, is the approach being developed in this report, details of which are discussed in other sections. In this section, some of the advantages and problems will be very briefly introduced.

In a digital data set, the information for an area is represented as coded computer values. With respect to the strip of imagery, each data point is referenced by an along-track and across-track distance. The measure of distance is usually the number of lines in the along-track direction and number of pixels in the across-track distance. Since each line and pixel has finite dimensions, the reference could be converted into metres in along-track direction and metres in across-track direction.

The above mentioned reference frame is with respect to the collection of the imagery with the along-track direction being the direction of aircraft travel. The geo-registration process (described elsewhere) references the data collection reference frame to the absolute (e.g., UTM, latitude/longitude, etc.) reference frame in which data are normally preferred.

A digitally mosaiced image is a combination of two or more digital images combined into one data set and referenced by a common coordinate system.

Digital mosaicing offers a flexibility which is not available with analogue mosaicing. For example, geometric scale errors and radiometric differences can be corrected, both across- or along-track. This is accomplished by specifying the coordinates of ground control points for geometric rectification and calibrated value for radar rectification. Once a mosaic is created, using the fullest resolution data, the data can be viewed at varying lower resolutions without repeating the entire mosaicing procedure, by merely averaging the full resolution data. However, the level to which these capabilities can be taken advantage of depends on having hardware which can perform the calculations within reasonable time constraints. The quantity of data will usually place limitations on the level of corrections which can be applied in a given situation, so that compromises will have to be made.

An important limitation of the digital mosaic is the window through which the results are viewed (i.e., the video display screen). The number of pixels is limited so that averaging or decimation must be employed to view a large area. The present STAR-VUE screen is 480 pixels in the vertical direction and 600 in the horizontal direction.

The STAR-VUE monitor can display an area of 11.52 x 14.40 kilometres with a resolution of 24 metres. In order to view a full swath width (approximately 46 km) on one screen, the resolution would have to be in the order of 75 metres. Studies are presently being performed to determine the data resolution beyond which the confidence of ice characterization/interpretation diminishes (INTERA, 1986).

Another difficulty occurs when the lines of pixels in different pieces of imagery are oriented at angles other than zero or 90 degrees. Mosaicing such imagery will require some resampling or other data manipulation before viewing on a video screen. Viewing imagery at some arbitrary orientation, e.g., north up, also requires some manipulation of the data before viewing. The computing requirements may place limits on how the data can be viewed.

Within these constraints, digital mosaicing is very attractive because of its flexibility in handling corrections as there is no need for film development facilities. Digital manipulation of the data offers other opportunities. For example, automatic ice classification will require a degree of sophistication in which mosaicing is only one step.

In the context of ice mapping there are three categories of digital mosaic product, these being:

1. Non-registered mosaics;
2. Partially registered mosaics; and
3. Fully registered mosaics.

The following sections briefly describe the three categories of ice mosaicing product.

Non-registered

A non-registered image contains no ground control points for geo-registration.

In NAV-ICE scenario, a type of non-registered image would be one which included the vessel. The relative location of ice features with respect to the vessel are identifiable. This is extremely beneficial since the vessel can avoid observed hazardous ice.

Partially-registered

A partially-registered image has a limited number of control points. Moreover, the control points are of low quality, being land features such as coastline or islands as opposed to discrete survey targets. Experience with ice management projects has indicated that along-track direction error compensation is usually sufficient. Experience with geological application of mapping radar has determined that the small scale RMS error can be reduced to less than 250 metres.

Fully-registered

A fully-registered image guarantees the accuracy of any given point to within a specified tolerance limit in any direction. Production of a fully-registered image requires a substantial grid of ground control points. Fully-registered images are not considered practical for ice management applications.

4.3 Existing Digital Mosaicing Systems

The problems of mosaicing imagery in digital format have been treated in various applications. An overview of the existing technology identifies a number of common problems and only a few variations in derived solutions and procedures.

An overview of some techniques used in existing systems follows.

PERCEPTRON COMPUTING

Perceptron Computing Inc. has developed an image analysis software package which is capable of handling image-to-image registration, geo-registration and mosaicing in a basic manner. Image-to-image registration can be performed by identifying common points on two images using cursor functions. Geo-registration is performed by correlating latitude and longitude entries to image points. The image is mapped to the ground coordinates by a polynomial transformation defined from the ground control points.

The Perceptron system requires the user to be familiar with an extensive dictionary of encryted commands. Furthermore, there is no well-defined technique or procedure to generate a mosaic.

DIPIX ARIES SYSTEMS

The Dipix Systems imaging analysis capabilities have been developed to meet the varied needs of the remote sensing community, with emphasis placed on Landsat MSS data. The Dipix System is a combination hardware/software package. A relatively simple mosaicing task is accomplished by geo-referencing two or more image files to the UTM coordinate system. Features are identified on the image and on the corresponding map from which coordinates are extracted. With these ground control points, a nearest neighbor or cubic convolution resampling can be performed to correct the image to the map as prescribed by a first, second or third order polynomial. Once this has been done for each image, they are registered one-to-another by means of the common coordinate system imposed on them. At this point, merging images into one file requires allocation of output space, and definition of the limits of the mosaiced area (i.e., north, south, east and west boundaries). The information within the areas of overlap is averaged, resulting in a slight "blurring" of the image.

The ARIES III presently under development will employ a number of more sophisticated techniques for image manipulation, registration and mosaicing. These will allow the user to register image-to-image without reference to a map projection, and to handle overlap area data more selectively, among other things.

INTERNATIONAL IMAGING SYSTEMS (I^2S)

International Imaging Systems have a fairly sophisticated image analysis system in their System 600. This system accommodates easy image manipulation such as roaming and zooming, as well as registration and mosaicing features.

Image-to-image registration is accomplished with both images viewed on a split screen, one being selected as "control". Homolouge points are then identified with the cursor on the screen. Image-to-image registration (geo-referencing) involves ground control points on a map being input in a digitizer or keyboard entry to match with the points identified on the image.

The I^2S system requires the user to have some familiarity and experience with the host computer system. Moreover, the system does not have a well-defined procedure requiring the user to string together individual tasks and perform file management.

4.4 Summary

The techniques outlined in these brief descriptions are all based on certain premises. The non-parametric approach (i.e., identification of common points and the subsequent definition of a mathematical model) assumes all necessary corrections to geometric distortions can be accounted for in this manner. In fact, rectification of some distortions can be determined from platform information and can be corrected by incorporating this information into a mathematical model.

Overall, most of the techniques examined are overly sophisticated for direct application in the context of an ice management system. However, components of these techniques could be implemented to accommodate the task of digital mosaicing of radar imagery. In particular, the ideas behind a basic translation and scaling (an affine transformation) could be employed if image flight lines were kept parallel, within certain preset limits. This would result in a simplification of the registration task by eliminating the need for rotation of data, a time-consuming pixel-by-pixel manipulation.

One important aspect of geometric distortion is minimized by the very nature of the ice being imaged. A general assumption of zero elevation can be made with little effect on the accuracy of registration if coastline edges and fixed marine points are the only ground control used. Other problems peculiar to radar imagery, such as layover, foreshortening and shadows, all exacerbated by elevation variations, will have little effect on image quality, especially if flight planning ensures appropriate look directions in areas with considerable coastal relief.

The problem of a non-static situation (i.e., one where the features image change positions with time) complicates the matter further. Existing techniques assume stationary control points, and therefore will not easily accommodate the dynamic situation.

4.5 Mosaicing Requirements and Standards

This section addresses the requirements of the user in an ice management scenario and defines standards which will influence the procedures and functions used to develop mosaics.

DEFINING USER REQUIREMENTS

With the benefit of the NAV-ICE System, vessels are able to navigate ice infested waters using a combination of SAR imagery and the marine radar display. For the NAV-ICE system, the relative position of the ice with respect to the vessel is the primary consideration. The absolute position of the vessl is only as important as it relates to navigation in safe waters. An exception is when the imagery is being produced, since it is difficult in some cases to identify and locate the vessel on the imagery without having a good approximation of location.

The NAV-ICE System is employed in two modes. First, the local mode, where the objective is the immediate avoidance of hazardous features, such as icebergs. In the local mode, the area of interest is approximately within a one-nautical mile radius of the vessel. Second, in the tactical mode, the objective is to select the optimum route through areas of hazardous ice. Typically, the tactical mode area of interest is within a 10 to 20 nautical mile radius that the marine radar can effectively operate.

For both of the aforementioned local and tactical modes a contiguous mosaic image is not deemed necessary since most ice management missions plan at least a 3- to 4-nautical mile overlap. However, image-to-image registration is necessary. To illustrate the need for image-to-image registration and the lack of need for a mosaic on the local and tactical scale, consider the tactical use of NAV-ICE. In the tactical mode the user identifies the vessel location on the SAR imagery by a correlation process, with the marine radar display. In order to improve the correlation process, the user plots and continuously updates the ship's track on the SAR image. As the vessel transits an area, its position on the SAR imagery may get nearer the edge. The area for correlation between the SAR image and marine radar image diminishes. On the other hand, the area for correlation on the ajoining image increases. Given four nautical miles of overlap and an eight-nautical mile marine radar effective range, approximately 70 percent of the marine radar display area can be correlated on the next image when the area on the preceding image is diminishing to 50 percent. Once the vessel location is identified on the next image, there is little need to reference the preceding image. In order to improve the identification of the vessel location transiting image-to-image, especially when the ice is moving, it is important that proper image-to-image registration be available.

On the tactical scale, the user, with the aid of NAV-ICE, is able to view full resolution data to select a route. The question that arises is, given a wider area of view will the user's route selection change? Given that dynamic ice almost always generates open water someplace, the answer is probably yes. Thus in order to select the long range route a larger area of view is required. This will give the user a better understanding of regional ice dynamics and ice characteristics.

It has been demonstrated on ice management projects and vessel transportation experiments that a regional or strategic view of the ice is required. In the strategic mode, the time planning time frame is in the order of days. It is understood that a substantial amount of ice motion may have occurred before the vesel gets to a specific point. Therefore, it is not critical to have accurate absolute positioning of the ice, but relative positioning with respect to the vessel and image-to-image registration is critical.

4.5.1 Defining Standards and Functions

As a result of the analysis of user requirements, a list of standards and functions required for mosaicing have been defined. The standards and functions are listed in Tables 1 and 2 respectively.

4.6 Proposed Mosaicing System

This section describes a proposed mosaicing system in the context of STAR-VUE. As a result, consideration has been given to reasonable hardware/software constraints and operational environments. The following section addresses the major components/ functions of the mosaicing capability.

4.6.1 User Interface

The proposed mosaicing system makes use of the existing STAR-VUE user interface. The user interface consists of a colour graphics screen and softkey menu driven system with a trackball. The mosaicing system requires an additional screen and a keyboard.

4.6.1.1 Viewing a Mosaic

The following focuses on how the user views the mosaic image. The proposed mosaicing system requires two screens. One screen is dedicated to the display of full resolution data and the other screen is dedicated to the display of the lower resolution mosaic. The full resolution screen is referred to as the DETAIL window and the lower resolution screen is referred to as the OVERVIEW window. The user selects the contents of the DETAIL window by roaming a frame on the OVERVIEW window to the area of interest, then initiates a selection.

It is proposed that the mosaicing system maintain the same screen layout as used currently in STAR-VUE. The screen layout consists, from top to bottom, of a status window, image display window, menu softkey window and message window. The present STAR-VUE screen has a maximum of 640 pixels in the horizontal direction by 480 pixels in the vertical direction. Given the aforementioned windows, the effective image display area is 634 x 387 pixels. Assuming a 24 x 24 metre pixel size (STAR-1 downlink) the maximum DETAIL window area of display is 15.2 x 9.3 kilometres (8.2 x 5.0 nautical miles). Assuming that data lines are displayed vertically, less than 20% of the STAR-1 wide swath data (approximately 25 nautical miles) can be illustrated on the DETAIL window.

It is proposed that the OVERVIEW window illustrate averaged or decimated data at a lower resolution. The optimum data reduction technique and the optimum resolution are factors which must still be addressed with further experimentation. Research on an unrelated project has shown that data averaged to 192 x 192 metres can retain adequate ice information. Given the same image display window limitation as used for the DETAIL window, the maximum OVERVIEW window area with 192 x 192 metre data is 121.7 x 74.3 kilometres (65.7 x 40.1 nautical miles). Again assuming data lines are displayed vertically, at least two swaths of STAR-1 wide swath data can be illustrated on the OVERVIEW window.

Figure 14 illustrates a mosaic produced by an analogue technique and reduced by a factor of three. Note that at a reduced resolution of 192 x 192 metres the user is not able to display on one screen the entire mosaic produced by a typical 4 line flight. In order to display the mosaic on one screen the image would have to be averaged/decimated to a resolution of approximately 400 x 400 metres. It is not clear at this time whether this resolution would be useful for the OVERVIEW window.

Given that the lowest acceptable resolution is 192 x 192 metres, it will be necessary to roam the OVERVIEW to examine the entire mosaic. The present STAR-VUE video memory boards allow a maximum of 2048 x 1024 pixels, which at 192 x 192 metre resolution gives an area of approximately 393.2 x 196.6 kilometres (212.3 x 106.2 nautical miles). The area of the video memory board is approximately equivalent to the maximum area which can be imaged in one mission of 4 parallel lines. Given the OVERVIEW window size of 634 x 387 pixels, only 12% of the video memory board area can be displayed at one time.

The same video board memory constraints as described for the OVERVIEW window apply to the DETAIL window. Given 24 x 24 metre data, the DETAIL video memory board can store an area of 49.2 x 24.6 kilometres (26.5 x 13.3 nautical miles). The entire area of the video memory can be displayed by a roam capability.

The aforementioned scheme attempts to optimize the video memory board and screen areas by storing and displaying lines horizontally or vertically. Orientation is provided on both the OVERVIEW and DETAIL window by a latitude and longitude grid overlay. It is judged easier to transform the latitude/longitude grid and coastline background map as opposed to the imagery.

As has been previously stated, the user selects an area to be displayed by roaming a frame over the OVERVIEW image. Once the frame is positioned over the area of interest, the DETAIL image is displayed

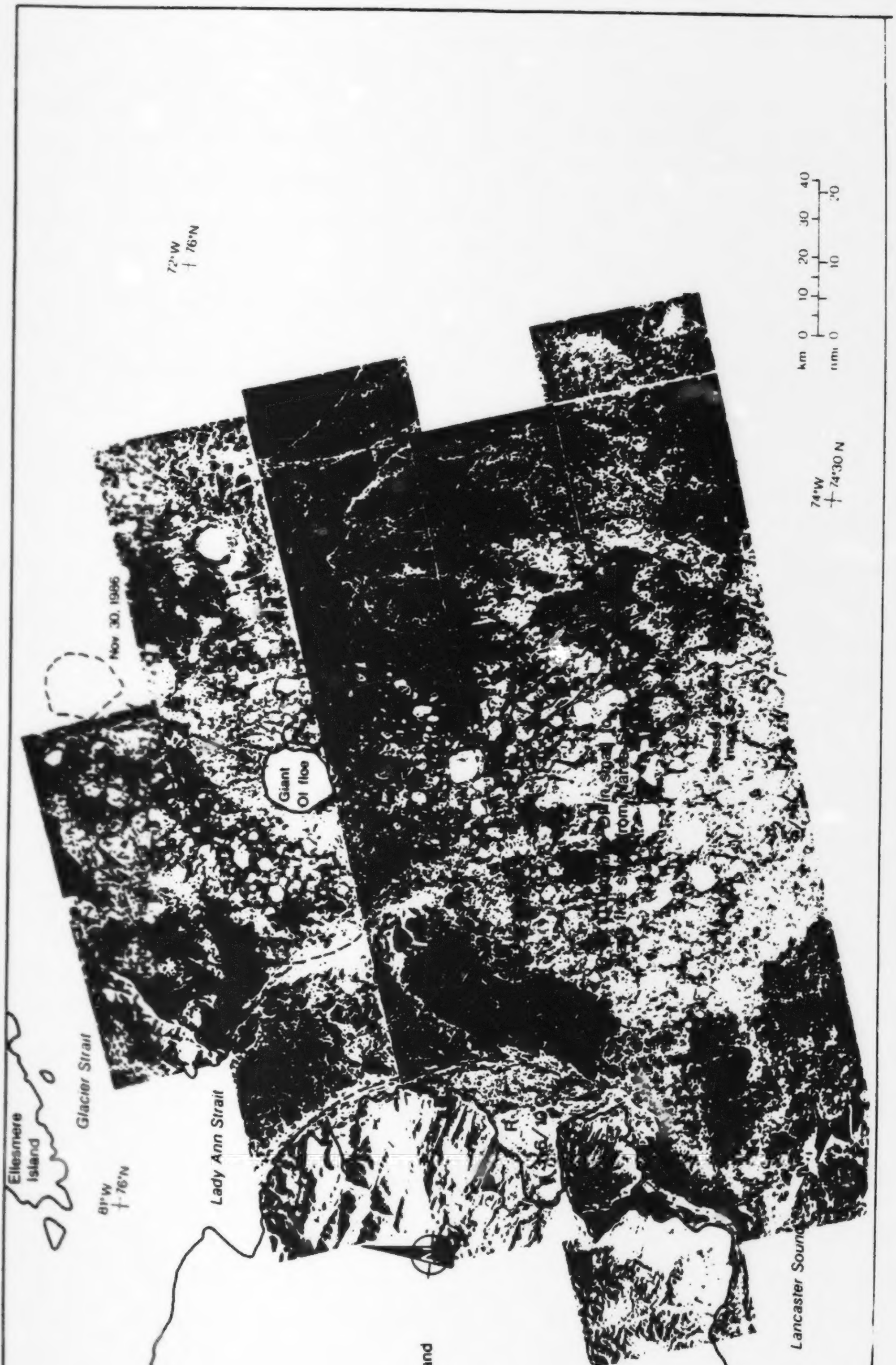

Ellesmere Island
Glacier Strait
81°W 76°N
Lady Ann Strait
Devon Island
Lancaster Sound
Nov 30, 1986
Giant Ol floe
72°W 76°N
74°W 74°30 N
km 0 10 20 30 40
nmi 0 10 20

Figure 14 Digital image mosaic of SAR data.

after a select command is issued. The speed at which the data can be displayed will be contingent upon how fast the data can be accessed off the storage media (usually disk) and how the data are stored. It is anticipated that the design of a system that defines the relationship between the OVERVIEW image and the DETAIL image will be a complex task.

4.6.1.2 Making a Mosaic

The following addresses how the user produces a mosaiced image. As pointed out in Section 3, geo-registration and image-to-image registration are two very important mosaicing tasks. Experience with analogue mosaicing indicates that in an ice management scenario, both of the latter registration tasks are performed on a strategic scale. For instance, in geo-registration prominent landmark features such as capes, embayments and islands are matched to a clear acetate overlay map or given known coordinates. For image-to-image registration, prominent features such as large floes or lead/ridge systems in the overlap area are utilized in the registration. The registration performed at the strategic scale was adequate for most ice management needs.

Based upon the aforementioned experience with analogue mosaicing, it is recommended that both geo-registration and image-to-image registration be capable of being performed on the OVERVIEW window.
The general STAR-VUE mosaicing task is summarized as follows:

1. Selection of MASTER image;
2. Geo-registration of MASTER;
3. Selection of first SLAVE;
4. Image-to-image registration of SLAVE;
5. Rectification of OVERVIEW image;
   (Steps 3, 4 and 5 can be repeated for additional images.)
6. Rectification of DETAIL images; and
   (Step 6 may be unnecessary in many cases.)
7. Storage of OVERVIEW image.

The following is a more detailed summary of the above summarized tasks.

1. Selection of MASTER Image:
   When the user initiates the MOSAIC functions, the STAR-VUE automatically displays the SELECT IMAGE screen which illustrates the individual flight lines. The user selects the MASTER image by merely moving the cursor to the desired flight line and clicking. The MASTER is defined as the initial geo-registered image to which subsequent images will be image-to-image registered. The corresponding averaging/decimated image is illustrated on the OVERVIEW window.
   In order to speed up the mosaicing process, it is

recommended that the image averaging/decimation be performed to some pre-specified resolution during the real-time downlinking.

The MASTER image is displayed on the OVERVIEW window such that the maximum image dimension corresponds to the video memory board maximum dimension. A latitude and longitude grid and coastline background map is overlayed the image according to the aircraft flight line coordinates.

2. Geo-registration of MASTER

   In an analogue ice management scenario, the imagery is rectified by along-track stretching and compression. This has been found adequate for ice management applications.

   For ice management mosaicing applications, it is proposed that geometric rectification be limited to along-track stretch/compression. Furthermore, it is proposed that the stretch/compression be restricted to linear adjustments between large scale control points. Large scale is defined to be control points with a separation on the order of 50 nautical miles.

   Based upon experience with analogue mosaicing, there are three viable techniques identified for mosaicing. These are described in a following section.

3. Selection of SLAVE Image:

   The selection of the SLAVE image to register to the MASTER is performed on the same select image screen and in the same fashion as described for the MASTER image selection.

4. Image-to-Image Registration

   It is proposed that image-to-image rectification be restricted to along-track lines stretch/compression as was the geo-registration.

   Cases where substantial ice motions are experienced present the greatest challenge to mosaicing. Depending upon the case, image-to-image registration has been foregone for geo-registration of individual data strips. Image-to-image registration is the identification of common features between two overlapping images. As was pointed out in Section ??, this is an important capability since it can provide the means to improve the geo-registration of imagery to containing ground control points. In an analogue mode, image-to-image registration is performed by identifying common features in the overlap area and overlaying the strips. This is usually best performed with film transparencies on a light table. Once the initial few reference points are identified, the registration process becomes relatively simple. The initial points are usually identified on a strategic scale and include major floes or lead systems.

   Based upon this experience, it is recommended that image-to-image registration be capable of being performed on both OVERVIEW and DETAIL scales.

At present, there are three possible means of performing image-to-image registratin. These are all similar in that the image to which successive images are registered is known as the MASTER. The image being registered is defined as the SLAVE.

4.6.2 Techniques for Image-to-Image Registration

4.6.2.1 Transparency Technique

This technique is most like the analogue image-to-image registration technique. One image is fixed and the adjoining image moved about until a match is achieved. Once a match is achieved, the image-to-image registration point is defined. After a sufficient number of image-to-image registration points are defined, the SLAVE image can be geo-registered (assuming the MASTER is geo-registered).

The film transparency is simulated by displaying the MASTER on the first four bits and the SLAVE on the remaining four bits of an eight-bit screen display. Analogue experience suggests that the initial match should be very close to final image-to-image registrations or this technique will not work satisfactorily.

4.6.2.2 Overlap Technique

This technique is advantageous for images which exhibit features of obvious continuity, for example, for landforms, coastlines and islands or for ice lead systems and ridge systems. This technique overlays one image on another, thereby covering up information on the bottom image. The top image must be moved back to view the contents of the bottom overlap section.

4.6.2.3 Point-to-Point Technique

In this technique, two images are butted together at adjoining edges and common points identified and marked. For example, a feature is identified and marked on the MASTER and then on the SLAVE. A line joining the two points is displayed to aid in the correlation between adjoining images. This technique is advantageous since it allows viewing of all data without interference in the overlap area. A disadvantage is that the overall area which can be displayed is limited.

4.6.3 Geo-Registration Techniques

4.6.3.1 Real-time Stretch/Compression/Translation

In this technique, the background map is held stationary and the image moved to provide the best fit. In addition to linear along-track stretch/compression, the only other rectification allowed is translation in both the along-track and across-track directions.

The proposed system actually allows the user to handle the imagery like hardcopy. Functions are proposed which will allow the user to translate the entire image and fix a point and stretch/compress a segment of imagery. This is referred to as real-time, since the actual rectification will be performed as the geo-registration is performed.

4.6.3.2 Point-to-Point Technique

This technique is very similar to the aforementioned technique in that coastal features identified on the imagery are referenced to a coastline background map. The difference is that the rectification is not real-time and the points identified on the imagery and background map must be explicitly defined.

This technique commences with the MASTER image and map overlay. Via cursor movements, the user selects a feature on the image and then moves the cursor to the corresponding point on the map overlay. This technique requires the landmark features to be clearly identifiable points such as the end of an island, etc.

4.6.3.3 Coordinate Technique

The coordinate technique is similar to the preceding described point-to-point technique except that the latitude and longitude coordinates are defined for each point selected off the image. This technique is especially applicable to navigation since the position of the vessel on the imagery can be defined in most instances.

4.6.4 Rectification

In both of the latter described image-to-image and geo-registration techniques, the common points and ground control points are merely selected and defined. The actual rectification is only performed as a result of a command to do so. The rectification must be performed as a background process to allow the user to perform other tasks.

4.7 Recommendations

This study has formulated the following recommendations:

1. The STAR-VUE system requires a mosaicing function to perform strategic tasks;
2. The mosaicing system should consist of two screens, one to display the low resolution mosaic OVERVIEW and the second to illustrate the full scale resolution DETAIL; and
3. In order to reduce computational tasks, limit the system sophistication by restricting data to specific configurations such as parallel flight lines.

5. MARINE RADAR DEVELOPMENT

A significant problem with using airborne radar imagery for tactical navigation is identifying the ship's position on the imagery. Keeping track of the ship's progress through the ice is also a complex task and generally the only sensor capable of accomplishing these tasks is the ship's own marine radar.

For tactical navigation, Marine radar provides the much needed connection between where the ice is at the time of the ship's passage and where it was when the airborne imagery was collected. By constantly tracking the ship's position in the airborne ice image with the marine radar, the airborne radar imagery can be used to steer the ship and avoid hazards.

For the most part, marine radar systems have been designed to provide optimum target (i.e., other ships, navigation buoys, etc.) detection in sea clutter and foul weather. They are designed to provide very reliable service, and to be easily repaired. They use very conventional technology and are sold to a very cost-conscious and relatively non-technical clientele. There is little or no provision in the average radar design for tracking the ship's location in a complex ice field.

For conventional navigation tasks, the marine radar has become the prime source of close tactical and tactical information. From the ice navigation viewpoint, however, its range is too limited for practical route selection. Thus, the main task for the marine radar, when in heavy ice, has become to locate and track the ship's progress on airborne radar imagery. In the presence of icebergs, or very low concentrations of ice, the target detection capability is of the utmost importance.

There are three basic requirements for an ice navigation radar. First, it must be able to detect weak targets at far range. Second, it should be able to detect targets in the presence of both sea clutter and bad weather. Both of these are aims of conventional radars. Third and unique to this application, the radar must be capable of making a 'picture' of the ice for comparison with the airborne radar imagery. It must be capable of producing an image of the ice that has range dependent gain removed so ice type signatures are stable over the near ranges. It should also provide the maximum possible coverage of the ice imagery, to permit registration with the SAR/SLAR imagery. This means retaining past imagery in a useful form for correlation.

The Display

The marine radar display is the one area where, in INTERA's experience, there is the greatest potential for cost effective improvements on marine radars, for ice navigation tasks. The standard display is the

Plan Position Indicator (PPI). The video is displayed on a cathode ray tube, with a very carefully selected phosphor. The display also has several electronic signal processing options built in, which have evolved over the years to aid in ship navigation. There is a variable gain control, to compensate for range dependent gain (S.T.C.); a form of high pass filter (F.T.C.) to remove rain and some sea clutter; and a form of constant false alarm rate threshold circuit. The phosphor has both a relatively bright response and a dimmer, very long term decay. This decay allows a form of scan-to-scan averaging and the response of the bright return forms a pulse-to-pulse averager which is reasonably effective.

There are two very serious drawbacks to these analogue displays. First, it is not possible to view the screen other than in nearly complete darkness, which entails looking into a hood at the screen. This makes it difficult to compare the marine radar data with other sensor data, e.g., SAR. It is also very inconvenient to store the data either as an electronic image, or as a photograph.

The second major drawback of the standard PPI is the unavailability of more than one level of brightness. Basically, returns are classed as target or noise by the electronics (under operator control). Targets are 'painted' bright white, noise is black. In complex ice fields, all the ice is painted bright and therefore saturates the display, making adequate definition of shapes and ice types very difficult. It has been shown that a multi-grey scale display can, for the most part, overcome this problem. With an adequate STC and several levels of grey scale in the return, quite complex ice fields can be imaged, in a fashion that is quite compatible with airborne radar imagery. This multi-grey scale may also of course be colour.

5.1 Proposed Development

During the MIDAS program, INTERA's radar image display system (RIDS) was used to validate the concept of working with both SAR and marine radar imagery for ice navigation. RIDS is a unique piece of equipment since it is able to process, display and record data from most commercial radars. It incorporates many advanced signal processing algorithms such as pulse-to-pulse and scan-to-scan averaging that are useful for imaging ice data. Data are displayed on a high quality colour video monitor and this display can be maintained indefinitely if desired.

Although RIDS was capable of displaying digital marine radar data and could be used to track the ship's progress on the airborne imagery, there are several problems that made it less than ideal for MIDAS.

The RIDS System

The RIDS system (Figure 15) has a 512 by 512 pixel display with 4 bits assigned to each pixel. There are two image buffers which allow the operator to flicker between two separate images to confirm targets or determine relative motion. The display can be viewed in either black and white or colour. The 4-bit display allows a number of intensity levels to be assigned to the returns from the ice.

RIDS also uses a colour to represent these intensity levels and is capable of assigning different radar return intensity levels to different colours on the video display.

The DRI (Digital Radar Interface) (Figure 16) built by INTERA for RIDS is capable of interfacing to a total of four radars. The RIDS system may control these radars through the DRI by selecting the radar and the range, or RIDS can be used as a slave display with no direct control.

The main interfacing problem encountered is in obtaining the antenna azimuth information since some manufacturers use resolvers while others use synchros and no standard exists among manufacturers for this repeater interface. The video and trigger are interfaced with a general analog input buffer consisting of an amplifier with gain and offset as well as inverters to adjust for inverted signals from some radars.

The video is digitized by a 6-bit analog to digital converter that is capable of digitizing analog signals at rates from dc to 30 Mhz. The azimuth information is digitized to 12 bits providing 1024 radials with actually only 512 radials being used by the RIDS systems.

Since the pulse repetition frequency (PRF) of the radar may change depending on the range selected, the DRI can be set to average 1, 2 or 4 radials to produce 512 radials for each scan. When 4 radials are averaged, the PRF from the radar must be greater than 2048 per rotation. This averaging of the radials provides improved signal to noise. The output of the adder buffer contains from 6 to 8 bits of significant information depending on the number of radials averaged. The digitized data consist of 254 range pixels and a 2-byte header containing the antenna position and handshaking signals for radar control from a radial block. The entire scan consists of 512 such radial blocks which are transferred to the RIDS microcomputer through a DMA (direct memory access) interface for further processing and display.

In the RIDS microcomputer the r, theta data are converted to an x, y coordinate system. Next, STC correction is applied to compensate for the range dependent effects of the radar return. The STC correction originally consisted of a subtraction from the intensity value (which represented an attenuation on the db scale for a log receiver). This was not the optimum STC for the digital ice data however, and INTERA has implemented a linear multiplication as a function of range to

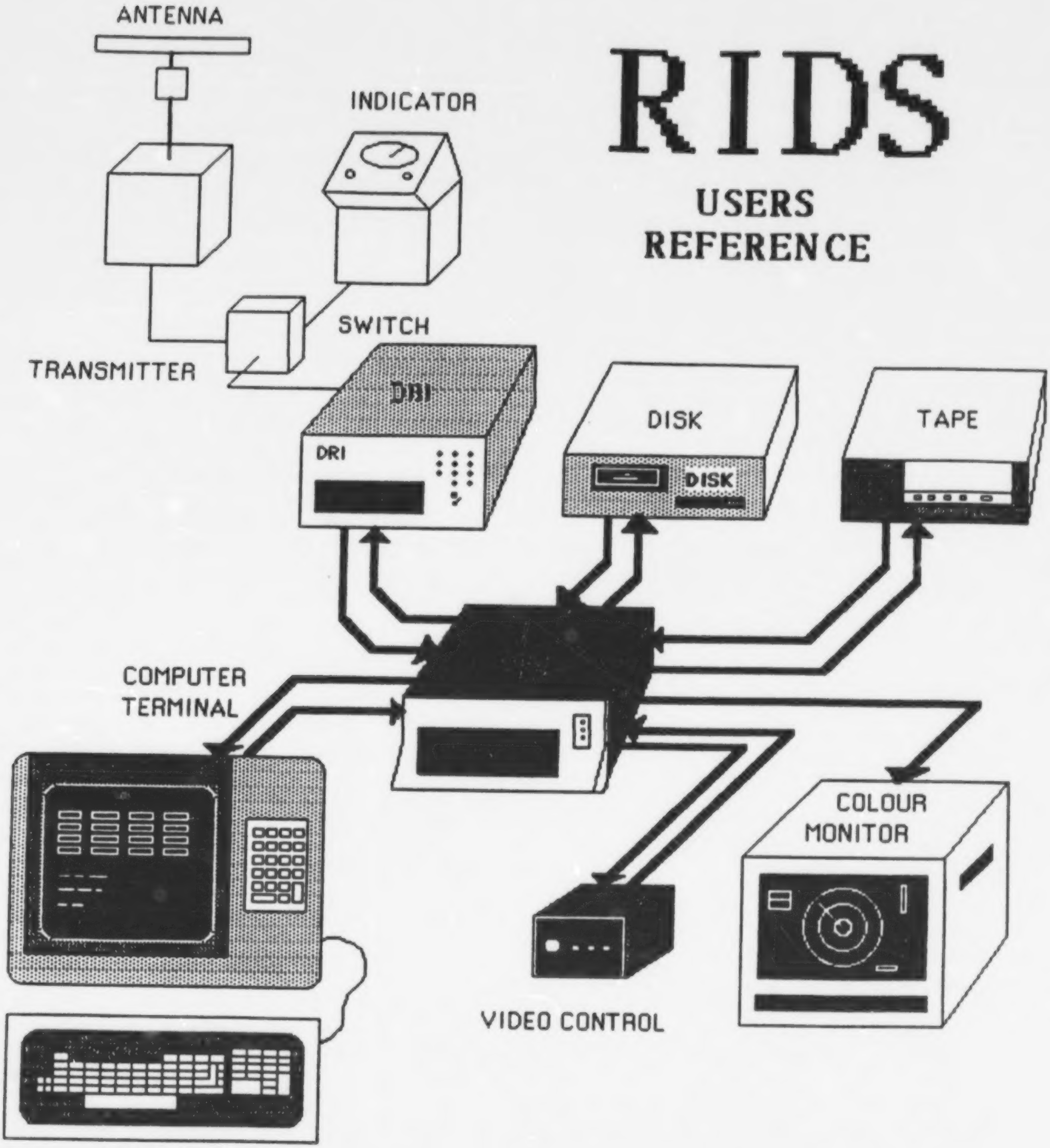
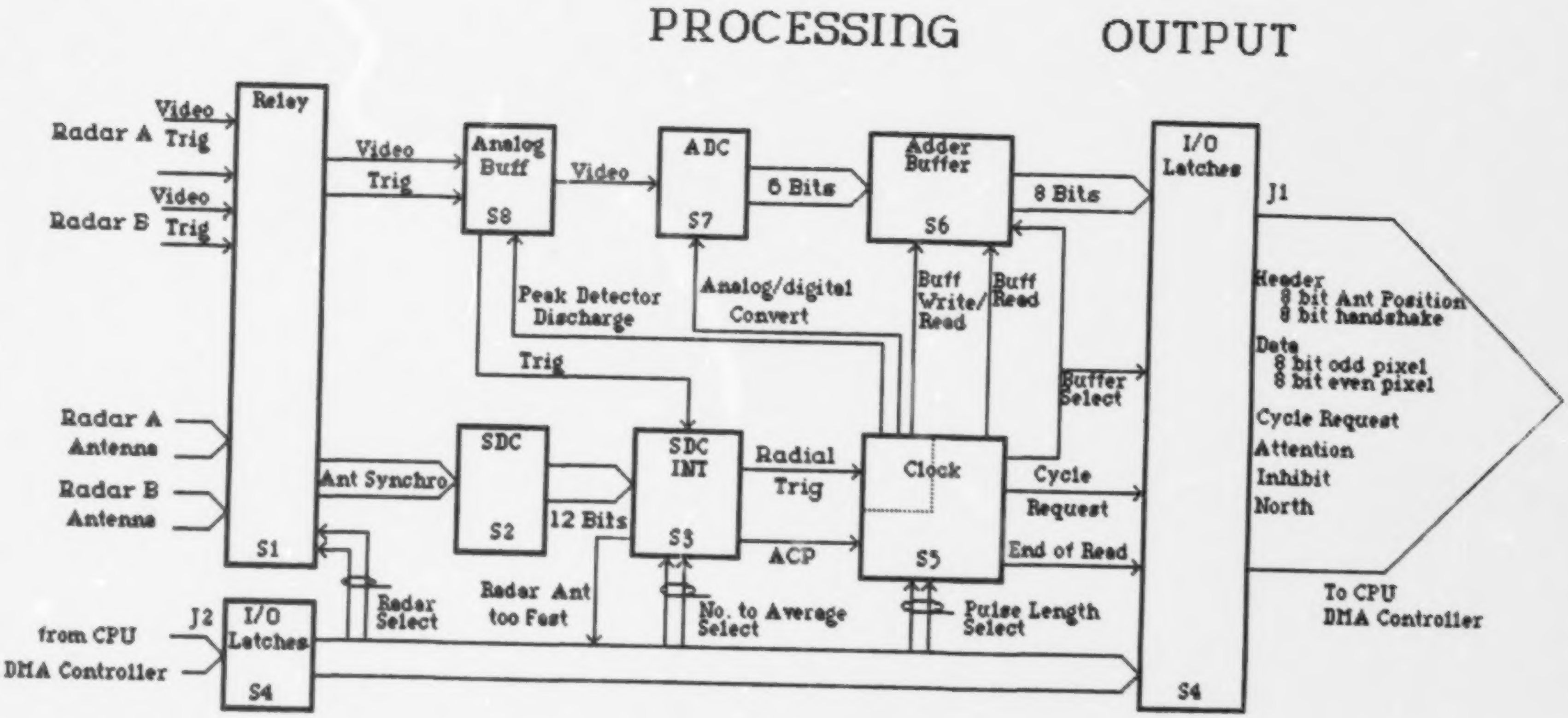

ANTENNA
INDICATOR
RIDS
USERS
REFERENCE
SWITCH
TRANSMITTER
DRI
DRI
DISK
DISK
TAPE
COMPUTER
TERMINAL
COLOUR
MONITOR
VIDEO CONTROL
KEYBOARD

Figure 15 Block diagram of RIDS system.


PROCESSING
OUTPUT
Radar A
Video
Trig
Radar B
Video
Trig
Radar A Antenna
Radar B Antenna
from CPU DMA Controller
J2
I/O Latches
S4
Relay
S1
Video
Trig
Ant Synchro
Radar Select
Analog Buff
S8
Video
Peak Detector Discharge
Trig
SDC
S2
12 Bits
Radar Ant too Fast
ADC
S7
6 Bits
Analog/digital Convert
SDC INT
S3
No. to Average Select
Radial Trig
ACP
Adder Buffer
S6
Buff Write/Read
Buff Read
Clock
S5
Pulse Length Select
8 Bits
Buffer Select
Cycle Request
End of Read
I/O Latches
S4
J1
Header
8 bit Ant Position
8 bit handshake
Data
8 bit odd pixel
8 bit even pixel
Cycle Request
Attention
Inhibit
North
To CPU DMA Controller

LEGEND

SDC - Synchro To Digital Converter

ADC - Analog to Digital Converter

S -1 to 8 board location

Figure 16 Block diagram of RIDS digital radar interface (DRI).

balance the radar display. The data then proceed through a lookup table to assign the colour that is to be displayed. The input of the normalized 6 to 8 bits is converted to the 4 bits available for display.

The present RIDS system has been criticized for being too slow. This is due to a number of factors present in the original design. First, insufficient memory was available on the PDP 11/23 system at the time of development. As a result, the disk drive is used to store data. Second, the complete RIDS software consists of over 300K of compiled code, which also results in a great deal of disk access. This disk access consumes about thirty to sixty percent of the CPU time. More memory cannot easily be added to the system since much of the software bypasses the operating system.

There are, however, several ways that the present system could be accelerated. These include: transferring the software to a faster processor with more memory (e.g., the PDP 11-73) and performing more of the operations in main memory, or performing more of the operations like r theta to x,y conversion in hardware.

In June 1985, INTERA recommended that Canarctic Shipping lease a commercial radar display system (JRC) to provide a bright real-time display of the marine data. INTERA interfaced this unit to the ship's Decca radar. It was proposed to TDC that a second marine radar display system be installed onboard the M.V. Arctic. This system was the INTERA RIDS, which was to be upgraded for this role. The RIDS was to be connected to the ship's radars and used as a standard with which to compare the JRC. The upgrades to the RIDS system were to include the replacement of the PDP 11/23 computer with the PDP 11/73 computer, the incorporation of a real-time scan averager, and a real-time data logging function.

5.2 Shipboard Trials 1985

Before the August voyage of the M.V. Arctic, several improvements were made to INTERA's RIDS system. These improvements consisted of:

1) A 2-times speedup of the display subsystem by modifying key software subroutines.

2) Upgrading of the data logging function to allow continuous logging of every radar scan. Note the previous software only allowed logging of data approximately every 10 seconds.

3) Modifications to the display subsystem to allow STAR-1 SAR data to be displayed on the RIDS computers. This was to test out the utility of displaying SAR data in full resolution on the ship. For the STAR-VUE design team, it was important to know what resolution was required on the display.

During the August voyage, the RIDS system was used to collect iceberg data while the ship was in open water from August 19 to 21 under a variety of different sea states. Radar images of sea ice were also collected while the ship was in heavy ice off Rea Point from August 22 to 27. These data were later used in the lab for analysis. Figures 17 and 18 show typical data that were recorded by the RIDs system.

Results

The JRC system functioned well but lacked the ship's heading mark and navigator functions, which are required by the ship's operators. The user interface to the system was also described as being very complex and difficult to use. The JRC also lacked an adjustable S.T.C. curve and variable offset, which meant that sometimes the display was saturated. The colour coding scheme was also found to be confusing.

On the other hand, the RIDS was much more flexible in enhancing the quality of the display. The scan-to-scan averaging function greatly improved the image quality when the ship was in heavy ice. While the display was adequate, the speed of the system was judged to be too slow for the quickly changing conditions when the ship was in open water and loose pack ice.

It was concluded that Canarctic should purchase the modules required for ship's gyro and navigator input for the JRC display to make it more useful. INTERA would continue to work on improving the RIDS system for the role of an ice navigating ship. It was decided that several hardware functions were needed on the RIDS, including a real-time scan converter to speed up the display, a hardware STC to prevent near range saturation, and a real-time scan averager. The user interface also had to be simplified since it was quite complex and required some knowledge of computers.

The project plan called for the implementation of several of these features for the M.V. Arctic's fall voyage. Unfortunately, the ship did not sail until the spring of the following year.

5.3 Folsom Scan Converter System

During the period from September 1985 to May 1986, several key decisions were made regarding the marine radar display. INTERA conducted a detailed design review to determine what was required to implement the required functionality with the RIDS system. At the same time, a market search was conducted to determine if any other hardware systems were commercially available for this role.

It was determined that the RIDS system would have to be redesigned to perform the majority of its function in real-time in hardware. This

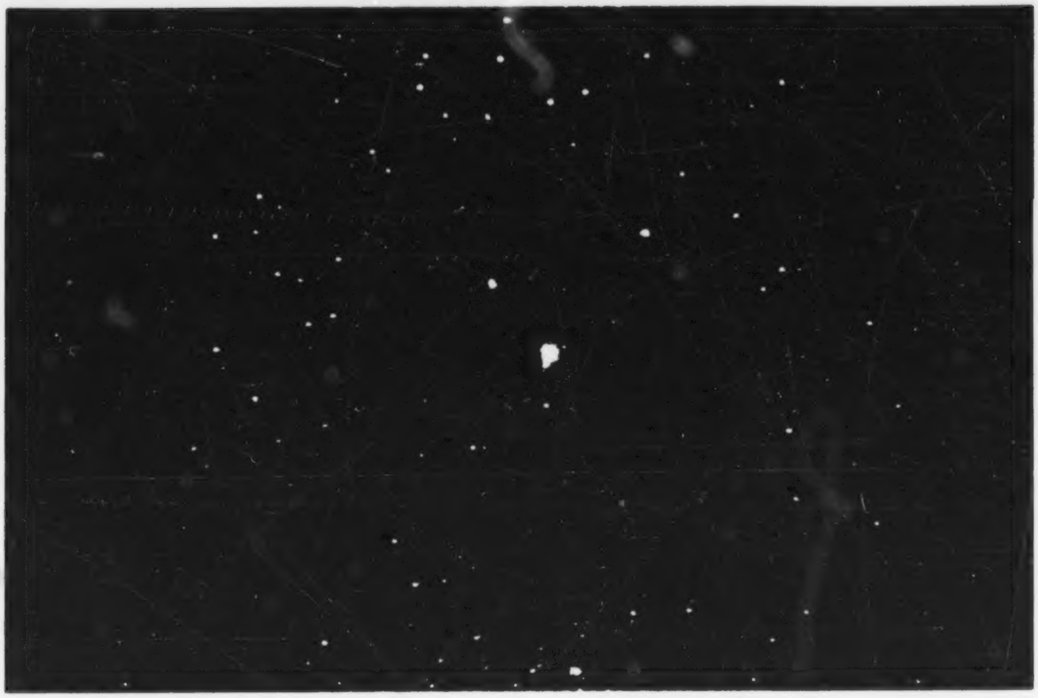


Figure 17 Typical data collected by the RIDS system. Icebergs in open water in Melville Bay.

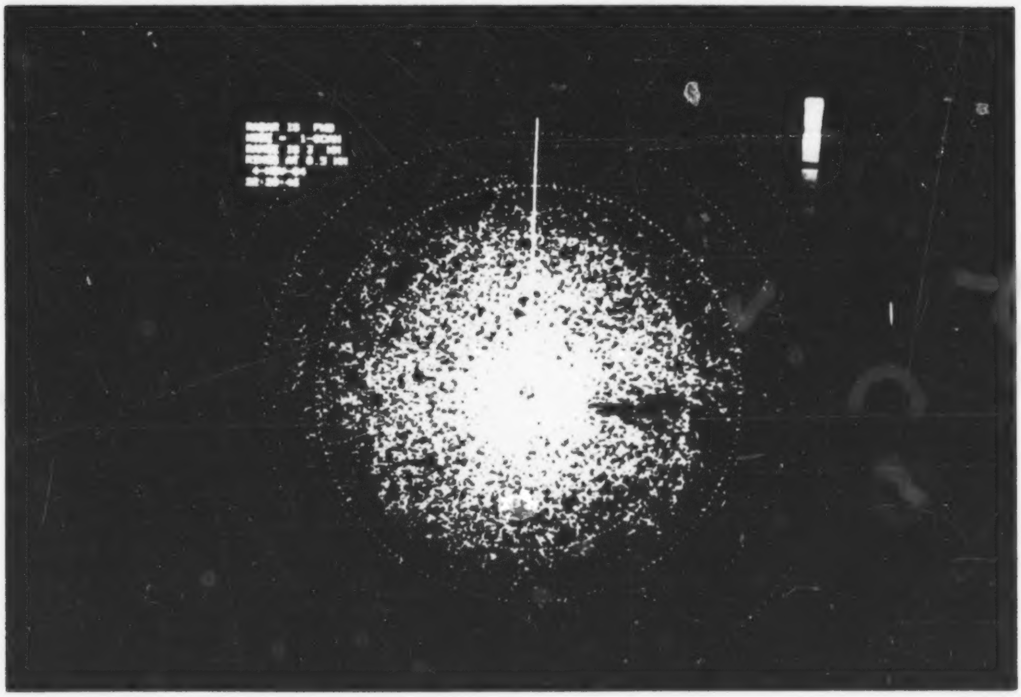


Figure 18 Typical data collected by the RIDS system. Heavy ice in the high Arctic. Note the moire pattern.

required a major redesign and equipment build. At the same time, however, INTERA discovered that a small California company called Folsom Research was manufacturing radar scan converters for the U.S. Military.

After a thorough evaluation, INTERA recommended to TDC that they purchase a Folsom scan converter for shipboard trial. The Folsom unit was a real-time radar scan converter that could be connected to a variety of radars. An interface was also available to allow exchange of data and control signals from any host computer. It was recognized that this system lacked many of the traditional functions required for a ship's marine radar display; however, it still provided the majority of functions required for the Ice Navigation display.

TDC purchased this unit in the spring of 1986 along with a personal computer and tape drive to be used for logging data from the Folsom unit. Software was developed for this data logging function.

During the spring of 1986, a plan was developed for the testing of the marine radar display systems. Because the Folsom Box was untested for imaging ice, it was decided that it should be compared to the RIDS for quality of display on the spring voyage of the M.V. Arctic. Both the RIDS and Folsom systems were installed on the M.V. Arctic in May 1986 for shipboard trial.

The testing on the M.V. Arctic was to involve a detailed comparison of the RIDS and Folsom units. Both systems were equipped to log data for later analysis in the lab.

In addition to the testing of the Folsom Box, the RIDS was also modified. There were two functions that it was felt the RIDS could be used to test. These included an analogue, a new hardware scan averager which could average any number of scans in real-time and an analogue STC curve generator which could be adjusted for different ice types. Both these features were incorporated into the digital radar interface (DRI).

Folsom Radar Scan Converter (Model 8342)

The Folsom Researchs Model 8342 Radar Scan Converter has been designed to digitize radar vector video and display it on a standard 525 line (RS-170) T.V. video output. This scan converter uses the latest in solid state technology by utilizing "Nibble Mode" dynamic RAMs for the display memory . The scan converter has minimal internal adjustments, thereby providing the user with years of maintenance-free operation. Some of the features of the scan converter includes a 6-bit radar image plane with three separate overlay planes, variable fade time constants, and a NON-VOLATILE RAM to retain the current commands and settings during power down.

The 8342 has four functional common modules which are shown in the

The 8342 has four functional common modules which are shown in the block diagram of Figure 19. The system specifications are outlined as follows:

Inputs:

Power: 90 - 132 volts 60 Hz

Radar Video: 1-to-5 volts (ground reference)
DC to 5 Mhz
75 ohm termination impedance
BNC connector

Trigger: 0-to-1 Khz
5 volt TTL level
BNC connector

Azimuth: Either 16-bit parallel TTL input with data valid line (DB-25 connector)
or
Synchro input
5 pin connector
Note: Synchro input levels and frequency depend on which Synchro/Digital Converter is installed.

RPM: Unlimited, but at high RPMs and low pulse rates some pixels will be skipped.

Origin: X and Y: +/- 10 volts for full screen offset
0 volts corresponds to center screen
Impedance: 1 meg
BNC connectors

RS-232: Two channels each 3 wire - transmit, receive, ground.

GPIB: 1 IEEE-488 GPIB connector

IRIG-B Code: 2 BNC connectors (1000 through)

Range Select: 4 TTL level signals
16 ranges from 10 nm to 225 nm
DB-37 connector

* Message Select: 19 TTL level signals (active low)
Message in customer supplied ROM
DB-37 connector

continued on next page

External TV Sync:	Composite sync (RS-170) Separate horizontal and vertical sync Impedance: 75 ohms BNC connectors

Outputs:

TV Video:	2 RS-170 composite video outputs (independently buffered) Impedance: 75 ohms BNC connectors
TV Sync:	1 RS-170 composite sync, TTL level Impedance: 75 ohms BNC connector
Message Displays:	19 customer supplied messages IRIG-B, Azimuth, Range, Offset Range Offset Angle, Fade messages
Memory:	512 x 512 x 9

Theory of Operation

The radar video data are first digitized to 6 bits in the 'flash' converter, then the data rate is lowered, as required in a 'peak' detector. This allows the system to have an arbitrarily fine resolution of an arbitrary range, in effect. This is made use of in their 'offset' model.

After 'down range averaging' in the peak detector, the data go through a (2^6 x 8) look up table (LUT). This is useful for such things as thresholding to remove noise, 'target' enhancement, etc. The LUT design is done in software and downloaded via the microprocessor.

The range data are digitized every Trigger pulse. The Folsom device can process up to 4000 radar radials per second. For a radar scanning at a 2 second interval, 8000 radials may be processed per rotation. The RIDS system by comparison can only handle 512 radials of 256 samples. No moire pattern results with the Folsom System. No pulse-to-pulse averaging is done the input processor, but is done in the video memory. No interference suppression is done at any stage.

Data are written into the video memory as they arrive from the ping pong buffer, through an arithmetic logic unit (ALU). They are written into the memory at the angle which is read from the 14 bit Synchro to Digital Converter (SDS). The ALU has 3 modes to account for the excess

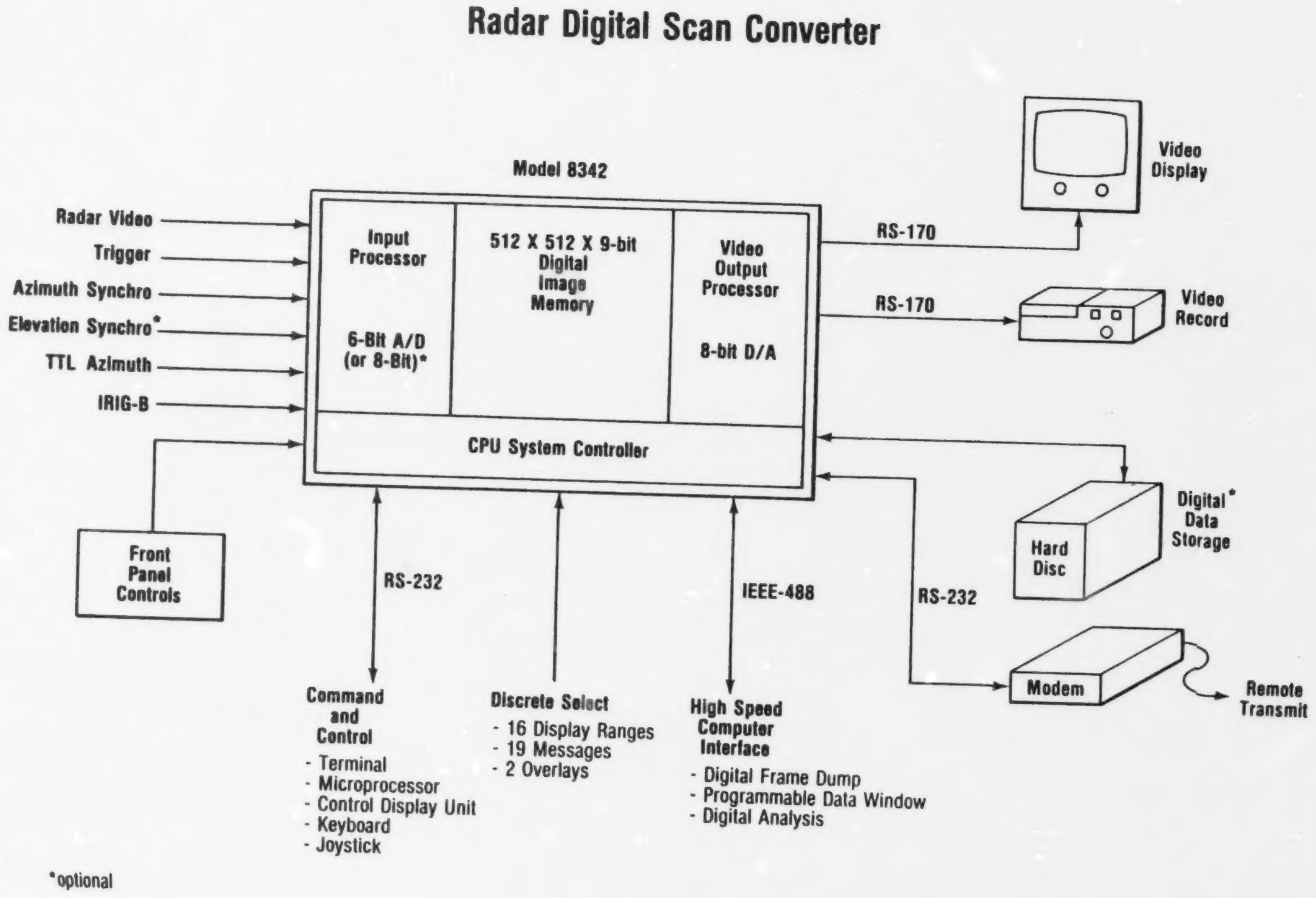

Radar Digital Scan Converter
Model 8342
Radar Video
Trigger
Azimuth Synchro
Elevation Synchro*
TTL Azimuth
IRIG-B
Front Panel Controls
Input Processor
6-Bit A/D (or 8-Bit)*
512 X 512 X 9-bit Digital Image Memory
Video Output Processor
8-bit D/A
CPU System Controller
RS-170
RS-170
Video Display
Video Record
Hard Disc
Digital* Data Storage
RS-232
Modem
Remote Transmit
RS-232
IEEE-488
Command and Control
- Terminal
- Microprocessor
- Control Display Unit
- Keyboard
- Joystick
Discrete Select
- 16 Display Ranges
- 19 Messages
- 2 Overlays
High Speed Computer Interface
- Digital Frame Dump
- Programmable Data Window
- Digital Analysis
*optional

Figure 19 Block diagram of the Folsom Scan Converter.

near range data: 1) Live, where the newest data point is displayed; 2) Peak, where the larger of the existing and new data point is displayed; and 3) Average, where the mean of the existing and new point is displayed. The average can be set as 1/4 new, 3/4 old. The selection between these modes is again software controlled.

In writing to the video memory, no pixel infill for far range is done. The 'read' into the video memory is done in nibble mode to ensure speed. This allows considerable flexibility for image processing, change detection, etc., in having two 4-bit images.

The 'Fade' on the video memory is very interesting, and offers an as-yet uncharted area of opportunity for image enhancement. During the video refresh cycle, the data are read out of the memory, to the display through a LUT, and back into memory. The LUT was designed to simulate a variable persistence phosphor screen but can do much more. The old data can be enhanced, etc. by use of this LUT.

The ability to move the origin of the x, y display allows an effective 'zoom'. For ships interested only in detecting small targets they are about to hit, or for data logging, this could be very useful.

The scan converter has 2 RS-232 ports: the Modem port, the Terminal port, and 1 GPIB port. The Terminal port is configured with a 16-byte buffer so that operators can control the scan converter through a terminal instead of the front panel.

The Modem port is configured with a 128-byte buffer and is set up to interface with a computer like the STAR-VUE host terminal.

Input Processor

A 6-bit A/D flash converter is the standard input processor. The video module accepts radar data to 5 MHz and video data to 27 MHz.

System Controller

An 8086-based 16-bit CPU provides master control and system interface functions. It contains 2 RS-232 and 1 IEEE-488 port. It also controls lookup tables in the INPUT and OUTPUT processor modules. An optional 8087 co-processor can provide 32-bit arithmetical operations such as fixed or floating point multiply or divide.

Memory Module

A high speed 512 x 512 x 9-bit image memory with nibble mode RAMS it utilized. One 1-bit image plane is dedicated for graphic overlays, cursors, annotations, video insertions and messages. The image memory is programmable into one or two memories for imaging processing functions.

Video Output Processor

An 8-bit D/A converter that generates 525 line, RS-170 output is the standard output processor. It includes lookup table functions for image processing and contrast enhancements, plus provision for an external sync.

Scan Converter Test

The Scan Converter Test will disable radar input and generate a series of concentric gray rings without the need of any external radar signals. This feature checks all the functions associated with the radar scan converter.

Overlay Selects

The two overlays can be independently selected or deselected by the Overlay Select commands. Overlay 1 ON enables all of the scan converter parameter displays along with the custom messages and the azimuth. Overlay 2 ON enables all the graphics features such as plotted lines and text characters.

Custom Message Select

The scan converter has 19 custom messages that can be selected either externally through the control port or internally through software commands. The location and content of each individual message is programmable through the Custom ROM.

Read/Write GPIB

The GPIB bus can be used to transfer images to and from the scan converter. The image transfer commands can be issued from either the two RS-232 ports or the GPIB port; the data transfer takes place via the GPIB bus only. The total number of data bytes transferred is 512 x 512 or 262144 bytes.

Image Intensity

The image radar display has an intensity level that ranges from 0, for 0.0 volts out, to FF hex, for 0.7 volts out of video output. This output level scales all of the values in the output lookup table for the radar image.

Overlay Intensity

The intensity of the Overlay is controlled by the Overlay Intensity command.

Input Lookup Table

The input lookup table is 40 hex bytes long high speed RAM used to convert the value of the radar input sample to an image value. The input lookup table can be reloaded with 40 hex values ranging from 0 to 3F hex. This reloading can be used to produce various log compression curves of the input radar data.

Output Lookup Table

The output lookup table is 40 hex bytes long high speed RAM used to convert the value of the radar image to an output video level. The output lookup table can be reloaded with 40 hex values ranging from 0 to FF hex. This reloading can be used to produce various log Expansion curves of the image radar data.

Fade Lookup Table

The fade lookup table is 40 hex bytes long high speed RAM used to convert the value of the radar image pixel to a new value once every fade cycle. This reloading can be used to produce various rates of fade on the image radar data.

Average Radar

The average radar input mode checks to see if the current pixel that is being written into was also written into during the previous radar vector; if it was then an average of stored data and the live data is stored at that location. If that pixel was not accessed by the previous radar vector, then the live radar image is stored.

Peak Radar

The peak radar command checks to see if the current pixel that is being written into was also written into during the previous radar vector; if it was then the peak value of the input radar and the image pixel is stored into the image RAM. If the stored pixel was not accessed by the previous radar vector then the live radar image is stored into the image RAM regardless of whether or not it was larger.

Live Radar

The live radar input will write new radar data into the image RAM on every vector. There is no checking for peak values or averaging of the radar image.

PPI Mode

The scan converter is initially set up in the PPI mode of operation. In this mode the scan converter operates like a standard PPI Display scope with the radar display in polar coordinates.

B-Scan Mode

In the B-scan mode of operation the radar display is swept horizontally across the display. The width of the display in azimuth degrees is determined by the previous width of the Azimuth Gate signal. The width of this gate is from 20° to 359°.

Freeze Select

The radar input data can be disabled by selecting the freeze on command. During Freeze the azimuth of the last written vector is displayed and is not updated until freeze is disabled.

Offset Angle

The Offset Angle command is used in conjunction with the Offset Distance command to move the origin of the radar vector to any position on the screen. The format for the angle of a decimal number from 0.0 to 359.9° with 0.0° at the top of the display, 90.0° is the righthand display, 180.0° is the bottom of the display and 270.0° is the lefthand of the display.

Offset Distance

The Offset Distance command is used in conjunction with the Offset Angle command to move the origin of the radar vector to any position on the screen. The format for the Offset distance is a decimal number from 0.0 to 225.0 knts. The Offset Distance will be clipped to the edge of the display if the distance exceeds the range for that part of the display.

Range

The Range Parameter is used to set the length of a vertical vector in nautical miles. This vector extends from the center of the display to the top. The horizontal vector is correspondingly scaled to be 4/3 of the vertical vector. The range of the scale factor is from 2 knots to 225 knots in increments of 1/10 of a nautical mile.

Graphics Overlay

The Graphics Overlay (Overlay 2) contains graphic symbols and text characters. The scan converter software provides subroutines for drawing lines and text. The Graphics Overlay is set up as a 512 horizontal by 480 vertical memory plane. All X, Y values must be in this range, otherwise they will be truncated. The upper left-hand corner of the screen is location 0, 0.

Character

The scan converter contains two character sets, a 7 x 9 and a 10 x 12 character cell. Bit 7 of the character byte determines which of the two sets will be displayed.

Move Cursor

A graphic cursor is used as the starting position for lines and text characters.

Plot Line

The line drawing subroutine will draw a line from the current graphics cursor location to the X, Y location following the Plot Line command.

5.4 Shipboard Trials May 1986

Both the RIDS and the Folsom systems were installed on the M.V. Arctic in Montreal in May 1986 for shipboard trial on the vessel's first voyage to the Arctic. Both systems were equipped to log data for later analysis in the lab. The RIDS system was equipped with a Kennedy tape drive for this purpose. An IBM-AT with an IEEE-488 bus interface was used to record data from the Folsom system. Radar scans from the Folsom system were subsequently logged to cassette tape using a Tallgrass 60 Mbyte tape recorder.

Two modifications had been added to the RIDS, one for STC and a second for scan-to-scan averaging. Unfortunately, the scan-to-scan averager failed to function as planned due to a defect in either design or implementation. The radar images therefore failed to register properly.

The new STC curve generator, however, performed very well. A qualitative evaluation of the STC curve generator resulted in several features near the ship being visible, features that would normally have been saturated. The fact that the STC curves could be modified in several ways provided a very flexible tool for enhancing near range features. The image quality of the ship's Decca PPI display and the Folsom display was found to be equal for the variety of conditions encountered. Unfortunately, the voyage was plagued with good weather, which limited the amount of testing and comparison that could be done. The Folsom display also appeared less granular than the RIDS, which made it easier to discern information. This is a rather limited statement, however, since only calm sea states were encountered.

Canarctic's JRC display was not functioning for this voyage due to hardware problems so no comparison with the Folsom display was possible.

Data were collected using the Folsom system for a variety of ice conditions under relatively calm sea states. These data were accompanied by full ship atmospheric and oceanic conditions and, when possible, photographs of pertinent features. Unfortunately, no RIDS data were collected due to a tape drive failure.

June 1986

Further comparison between the RIDS and Folsom system were made during the voyage of the M.V. Arctic from Antwerp to the Arctic. The image quality of the Folsom system compared reasonably with the PPI in the calm conditions encountered. Sea clutter suppression was not available on the Folsom unit so near range clutter was flagged as a potential problem in rough seas and in heavy ice.

The displayed resolution of the Folsom system was much better than the RIDS due to the scan conversion method used in the Folsom system. By sampling every pulse, noise patterns did not show up on the display. This was a problem with RIDS. More data were collected during the voyage for lab analysis. The JRC was still not functioning due to lack of service support from JRC Japan.

August 1986

The Folsom system was used onboard the M.V. Arctic for the Bent Horn voyage. No specific program was conducted by INTERA personnel so Canarctic personnel were encouraged to provide feedback. They were critical of the lack of nautical functions available on the system since they were used to a PPI display. The main complaints were:

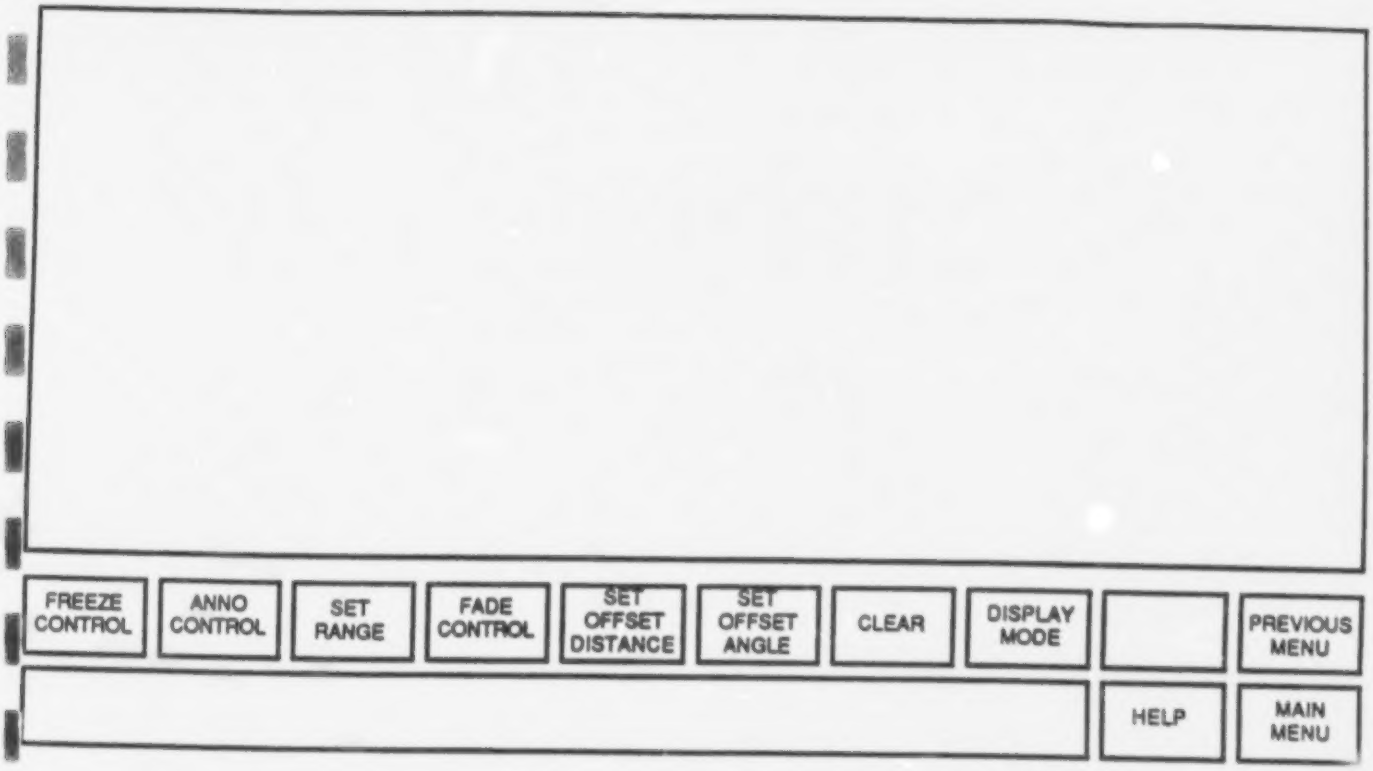
Lack of STC to reduce near range clutter;
Lack of ship's heading mark;
Lack of cursor for range and bearing read-out;
Lack of range rings; and
No ship's gyro or speed log input.

October 1986

New software and hardware were brought to LCI to try the first integration of the Folsom system with the STAR-VUE system. This addition to the STAR-VUE system was called MARINE-VUE.

A single asynchronous interface (DLVEI-M) was introduced into the STAR-VUE backplane in order for STAR-VUE to communicate with the Folsom system. A new set of menus was also added to the STAR-VUE system to control the Folsom box via an RS-232 interface. Figure 20 shows the typical MARINE-VUE menu presentation. The functional specification for the first MARINE-VUE menus are documented in Appendix A of this report.

The menu system worked well; however, the main drawback with the implementation of MARINE-VUE was the inability of the system to rotate the image to the same orientation as the SAR image on STAR-VUE. This made it extremely difficult to match the SAR and marine radar.


FREEZE CONTROL
ANNO CONTROL
SET RANGE
FADE CONTROL
SET OFFSET DISTANCE
SET OFFSET ANGLE
CLEAR
DISPLAY MODE
PREVIOUS MENU
HELP
MAIN MENU

MARINE VUE

Figure 20 Typical MARINE-VUE menu available on the STAR-VUE system.

No data were logged during this voyage. The RIDS system was also run occasionally but the performance of the Folsom system was so superior to the RIDS in terms of displayed resolution that the RIDS was not favoured by the ship's personnel. No further experiments were done with the RIDS system.

5.5 Results

During the period September 1985 to September 1986, several key decisions were made regarding the marine radar display. It was determined that the INTERA RIDS system would have to be redesigned to perform the majority of its functions in real time if it was to be used for ice navigation. A market search revealed that the only commercially available unit which could serve this role was a scan converter manufactured by Folsom Research Inc. During the 1986 shipping season, both the RIDS and Folsom units were tested extensively on the M.V. Arctic. The Folsom unit was found to be a much higher quality display unit than the RIDS because data are digitized into video memory. The Folsom unit was also a real-time display, which was required for a rapidly moving ship. The scan averager that was implemented on the RIDS failed to perform as expected due to hardware problems. Because of the success of the Folsom unit, further work on RIDS was abandoned. The data collected from both these systems were later used in the lab to further refine the requirements for an ice imaging radar.

During the fall of 1986, the STAR-VUE interface was modified to include the operation of the Folsom unit. This allowed the radar display to be controlled from a single console. This approach worked extremely well and made it easy to control the radar using only the system trackball.

5.5.1 Lab Experiments

During the course of this program, a great deal of data were collected using the systems that have been outlined above. These data have been used primarily for the qualitative assessment of display resolution. From the data collected, it is clear that the Folsom unit is a far superior scan converter than the INTERA RIDS. In addition to this, the collected data have also been used in a series of experiments designed to improve the system functionality for NAV-ICE. Several digital enhancement techniques have been applied to the marine radar images for iceberg detection. Data have also been used for comparison with SAR imagery and to simulate marine radar data from SAR data. This is the subject of another TDC report (TP8221E). Finally, an expert system shell called M1 has been evaluated for its role in processing target detection and tracking marine radar data.

5.5.2 Iceberg Feature Enhancement of Marine Radar Images in Sea Clutter

It has been stated previously that for the most part, marine radar systems have been designed to provide optimum target detection in sea clutter and foul weather. From the ice navigation viewpoint, however, its range is too limited for practical route selection. Thus, when airborne SAR is available, its main task is to locate and track the position of the ship on the SAR imagery. In the presence of icebergs or very low concentrations of ice though, the target detection capability is of the utmost importance.

Several experiments have been conducted during the course of this program which examined the application of digital enhancement techniques to marine radar images for iceberg detection. The primary reason for this research was to determine if such techniques and functions would be useful additions to the MARINE-VUE system.

The problem of iceberg detection has been extensively studied since the time when marine radar was first put into service by the French in 1935. Half a century later, people are still trying to find better solutions to the problem. Detecting floating icebergs is complicated due to many factors, including variations in size, shape, aspects presented, surface conditions and height above the water of each iceberg, all of which will vary the radar cross-section (r.c.s.) of the targets. In addition, the r.c.s. of the iceberg will be modified by interference from the sea in the form of sea clutter returns, and the interference will be a function of sea state and even wind direction.

The problem of iceberg detection is further complicated by the various types of radars, each designed to detect only a limited class of targets. Most radars are designed to detect aircrafts, ships, or buoys. Each type of radar requires special functional capabilities, such as, for example, moving target indication (MTI) for aircraft detection. Therefore, the design of a suitable radar system for the purpose of iceberg detection can be regarded as a problem area which needs considerable attention.

Since the fall of 1983, marine radar image data have been systematically collected during several Arctic voyages carried out by the M.V. Arctic. The data for this project were recorded by INTERA's Radar Image Display System (RIDS) onto CCT tapes in a variety of sea and ice conditions. The hardware system used was the ship's DECCA X-band non-coherent radar.

Ice and Iceberg Classification

Sea ice differs from fresh water ice in that it has impurities contained in its ice matrix. The impurities present are mostly brine inclusions and air bubbles. The main factors which influence formation of sea ice are the brine content of the surface water, the vertical distribution of the salinity, the surface temperature and the depth of water. Other factors, such as wind, sea state and the intensity and rate of cooling, also affect the formation of sea ice.

First-year ice consists of a primary layer of frazil or randomly oriented columnar ice followed by a much thicker layer of large, vertically oriented columnar crystals. Frazil ice forms in super-cooled turbulent water, whereas columnar ice forms in calm water under already existing ice cover.

The surface of multi-year ice is not smooth; it has undergone an extensive process of recrystallization during the summer melt cycles and consists of an array of refrozen meltponds and hammocks. The upper layer of recrystallized ice, which has a widely varying density (around 0.7 g/cm^3), merges into a layer of recrystallized ice of slightly higher density, and then into a lower clear-ice layer of density between 0.8 and 0.9 g/cm^3. The salinity of multi-year ice is much lower than that of first-year ice, typically less than 1 part per thousand near the surface, increasing to 2 or 3 parts per thousand in the bulk (clear) ice. This much lower salinity is due to extensive drainage of brine from ice during the summer melt period. The salinity of first-year ice is about 5 parts per thousand. The surface topography of first-year and multi-year ice is given in Table 1.

Unlike sea ice, icebergs are pieces of ice that have broken away from a glacier, which is a mass of snow that forms on land over millions of years. Icebergs, therefore, consist of freshwater ice, with up to 15% covolume of air, introduced when the snow compresses and recrystallizes to form glacial ice. The mean density of icebergs is about 0.86 g/cm^3. In Table 2, icebergs are classified into three classes according to their size.

Sea Clutter

The ability of a radar to detect a target on or above the sea level can be limited by sea clutter as well as by receiver noise. By definition, ^{o} is the surface clutter cross-section per unit area, $_c$ is the radar cross-section from surface area A_c, the following relation holds:

$$\sigma^o = \sigma_c / A_c . \tag{1}$$

The return power p_c from the clutter is described by the surface clutter radar equation:

$$p_c = p_t \, G \, A_e \, \sigma_c / (4\pi)^2 R^4 , \tag{2}$$

where p_t = transmitter power,
G = antenna gain,
A_e = antenna,
R = radar range.

Table 1. Surface Topography of Sea Ice

ice type	ice surface	ice floe edge character	snow cover on ice	characteristics of rafting and ridging
first-year ice	smooth	angular	little or free	sharp edges and newly formed
multi-year ice	rough	rounded	thick	weathered and rounded

Table 2. A Classification of Icebergs

berg type	weight (tons)	above water height (m)	surface area (m^2)
icebergs	> 5400	> 5	> 300
bergy bits	120-5400	1-5	100-300
growlers	< 120	< 1	20-100

With help from Figure 1, $_{c}$ can be written as:

$$\sigma_c = \sigma^0 A_c = \sigma^0 R\theta_B(c\tau/2)\sec\phi \, . \tag{3}$$

where = radar pulse length,
$_{B}$ = azimuth angle,
= grazing angle.

Substituting expression (3) into (2), the clutter power p_c can now be described in another form:

$$p_c = p_t \, G \, A_e \, \sigma^0 \, \theta_B(c\tau/2)\sec\phi \, / \, (4\pi)^2 R^3 \, . \tag{4}$$

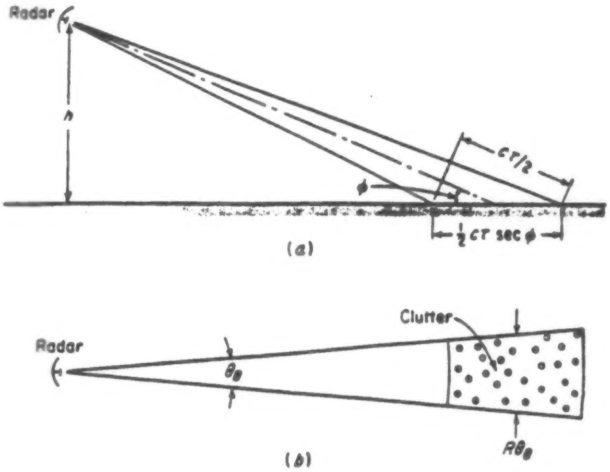


Figure 21. Geometry of radar clutter. (a) elevation view, (b) plan view.

The signal power p_s returned from a target with r.c.s. $_{t}$ is given by:

(5)

Combining equations (4) and (5), a very useful parameter called the signal-to-noise ratio, p_s/p_c, or simply S/C, is obtained:

(6)

Note that the echo from surface clutter varies inversely as the cube of the range, rather than as the fourth power, as is the case for point targets. This means that the sea clutter return will not fade as quickly as the point targets.

If the maximum range R_{max} corresponds to the minimum discernible signal-to-noise ratio $(S/C)_{min}$, the expression (6) can be written as:

(7)

Thus we can see from equation 7 the main factors affecting the detection of targets in the presence of clutter are the pulse width and beamwidth of the radar.

The mean cross section per unit area ^{o} of sea clutter is also known to vary with grazing angle (can be adjusted by antenna height), with frequency and with polarization. An illustration of these variations for average sea environments with wind speed ranging from 10 to 20 knots is given in Figure 22.

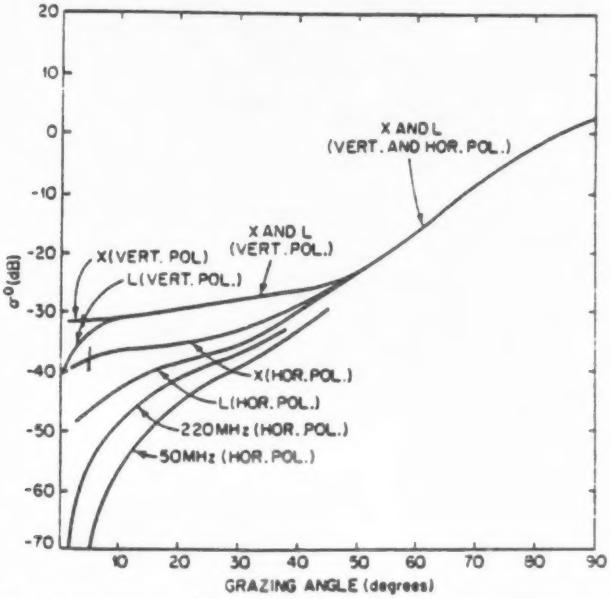


Figure 22. Variations of ^{o} with respect to different parameters.

Although numerous experiments have been performed to investigate the sea clutter on a qualitative basis, the basic phenomenon of sea clutter on a quantitative basis has not yet been definitely established. However, it is well known that sea echo from waves acts as a built-in jammer, blanketing and obscuring small target echos such as growlers and bergy bits. Other things being equal, the strength of the sea return depends largely upon the wind force. Experiments have shown that the range of sea clutter on the scope is nearly a linear function of the sea state.

From equation (7), it is clear that a radar performance is intimately linked to the signal-to-clutter ratio. People have attempted to measure the S/C ratios with respect to different sea conditions, which are classified by the World Meteorological Organization and given in Table 3.

One of the notable works was conducted by the U.S Coastguard in a two-year classified study of the detection of discrete lumps of ice in 1945/46, off the coast of Grand Banks, Newfoundland. The signal-to-clutter ratios from a target at 5,000 yards were measured with both X-band and S-band radars under varying sea conditions, and the results are shown in Table 4. A more recent work of similar kind, using a pair of radar operated at 3.2 cm wavelength but whose other parameters regarding beamwidth and pulse length varied significantly, was reported by Williams in 1972. A summary of the experiments are given in Table 5.

Both the works by the U.S. Coastguard and by Williams have indicated that a low resolution radar system performs somewhat better in terms of signal-to-clutter ratio under smooth or very rough seas than does a high resolution radar. But the situation reverses when the sea state is slight to moderate.

It is an established fact that signal-to-clutter ratio varies with respect to different sea environments, as well as different radar parameters. Moreover, it is well known that target signal return varies significantly in calm sea, so that the radar equation (5) requires modification. The above phenomenon is named the multi-pathing effect, or Lloyd's mirror effect.

When the antenna and target are near the surface of the sea, as in the case of iceberg detection by shipborne marine radar, interference effect can occur between the direct and reflected radar beams. If one considers the sea surface to be a flat, reflecting plane (a reasonable assumption for a calm and glassy sea state) with the radar antenna located at height h_a, the target at a height h_t and a distance R from the radar as illustrated in Figure 23, the energy radiated from the radar antenna arrives at the target via two separate paths. One is the direct path from radar to the target, and the other is the path reflected from the surface of the sea. Therefore, the magnitude of the received echo signal will depend on the amplitudes and relative phase difference between the direct and the surface-reflected signals.

Table 3. Sea States

Sea States	Wave Height (m)	Descriptive Terms
0	0	calm, glassy
1	0-0.1	calm, rippled
2	0.1-0.5	smooth, wavelets
3	0.5-1.2	slight
4	1.2-2.4	moderate
5	2.4-4.0	rough
6	4.0-6.0	very rough
7	6.0-9.0	high
8	9.0-14	very high
9	> 14	phenomenal

Table 4. Results of the U.S Coastguard Study

Sea States	S/C Ratios X-band Radar	S/C Ratios S-band Radar
smooth	6	17
slight	11	10
moderate	8	5
rough	3	6
very rough	0.2	1.5

Table 5. Observations on Various Ice Targets (Williams [8])

Targets	Sea State Swell (ft.)	Windforce	First Range Seen on Approach (nm)	
			High res. set	Low res. set
growlers	10-12	7	never seen or recognized	0.6
growlers	10	5	0.5	1.2
growlers in pack ice	5	3	3	2.5
pack ice	5	3	12	2
ribbon ice	5	3	12	4
mush and bread ice	4	3	Ice never spotted by either radar	

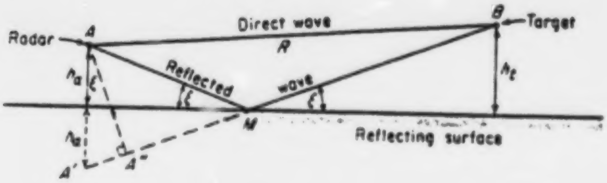


Figure 23. Propagation of radar beams over a plane reflecting surface.

Thus the presence of a plane reflecting surface causes the continuous elevation coverage to break up into a lobed structure. A target located at the maxima of a particular lobe will be detected at a range twice that of the same radar located in free space. However, at other angles, the radar detection range can be less than the free space range. When the target lies in the nulls, no echo signal is received. The angle of the first (lowest) lobe is approximately equal to $/8h_a^2$. If low angle coverage is desired, the radar antenna height should be high and the wavelength of the radar beam short. The antenna pattern lobes caused by the presence of the sea surface might sometimes be of advantage when the longest possible detection range is desired against low targets and where continuous coverage is not required.

Since the theoretical treatment on multi-pathing predicts that the radar coverage be discontinuous, the target signal return in a calm sea state should also be discontinuous.

A sequence of continuously recorded marine radar images from a calm sea state was recorded onboard the M.V. Arctic with the RIDS system has been used to illustrate this point. A strong target signal return in the images was selected and its gray level values in a 3 by 3 window were measured, along with the range and bearing with respect to the radar. A plot of the gray level values as a function of range is displayed in Figure 24. Note that the range is measured in pixels. The results have shown unequivocally the varied signal returns, as predicted by the theory.

It is clear from the discussion above that two major tasks are involved in designing an iceberg detection and ice imaging marine radar system. One involves changes in the marine radar hardware in order to better match the target characteristics. These changes include changes to frequency, polarization, pulse length, etc. The second is the application of digital processing techniques to more effectively convey to the operator relevant information contained in the radar returns.

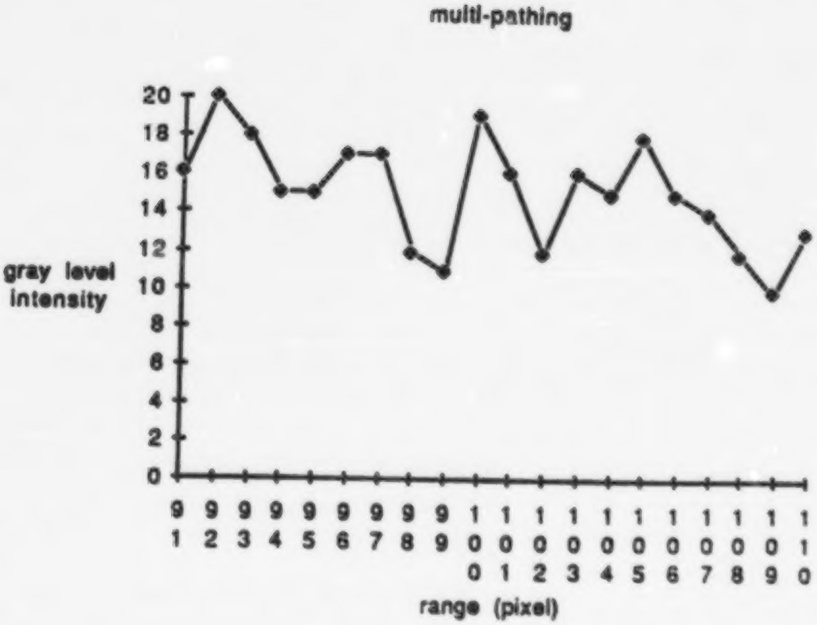


Figure 24 Measurement of target intensities in calm sea state.

One of the advantages of digitally processing the marine radar data is that special tracking features can be built into future display systems since a time history of the image can be recorded. Although not the focus of this study, it is evident that automatic tracking and monitoring functions for distributed and point targets can be made available to ships equipped with advanced display systems.

Digital Enhancements of Marine Radar Images

One of the objectives of the work done during this project was to evaluate the effect of applying a few standard digital image processing techniques to enhance iceberg features in marine radar images. This was not meant to be a comprehensive study but rather a feasibility study of this approach to post processing.

A digital image is a plane of integer values. An element of a digital image is called a pixel, and the integral value associated with it is called its gray level. A digital image usually consists of a very large number of pixels. For example, a typical marine radar image is a rectangular array of 512 by 512 individual samples which are quantized to 64 discrete gray levels, i.e., to a 6-bit number. Therefore, one radar image needs approximately one and a half million bits of memory.

There are two important types of operations that may be applied to a radar image.

1. Point operations: the output gray level at a point depends only on the input gray level at the same point. Such operations are extensively used for gray scale manipulation, and for segmentation by pixel classification.

2. Local operations: the output level at a point depends only on the input levels in the neighbourhood of that point. Such operations are used for deblurring, noise cleaning, and edge and feature detection, among many other applications.

Two major factors which may adversely affect the quality of a radar image are sea clutter and receiver noise. Reducing these artifacts is the main objective pursued here. Applying a few standard signal processing techniques to the digital marine radar images gathered under different sea conditions was considered an initial step in the investigation. Any positive results coming out of this were hoped to be implemented in future real-time radar image display systems.

A variety of two-dimensional digital filters could be applied to an image, but local operators were found to be the most attractive. Local operators perform filtering operations in a small neighbourhood (usually 3 by 3 or 5 by 5) of a window pixel. Local operators afford linear or non-linear filtering with a minimum amount of memory space and greater amenability to real-time implementations. Local operators may also be easily selected to fit in an adaptive filtering scheme with parameter dependency on picture feature and quality. A normal criterion for filter performance is its ability to suppress noise-induced artifacts and sea clutter while enhancing relevant features such as iceberg returns.

Two kinds of linear local operators were therefore considered for application - edge detection and Laplacian filters. The edge detection filter with filter size 3 by 3 or 5 by 5 computes the mean absolute difference between the gray level value at each pixel and at each neighbour in the filter window surrounding the pixel. The result of an edge detection filtering is an image where higher gray level values indicate the presence of an edge between two regions. The Laplacian is a differential filter and the effect of applying a Laplacian to an image is to highlight the gradients in the image, with high gray level values usually indicating an abrupt change in gray level values in the original image. The Laplacian filtered version of an image normally appears sharper. In mathematical parlance, the two-dimensional Laplacian of a function f is defined as

$$\Box^2 f = \partial^2 f/\partial x^2 + \partial^2 f/\partial y^2 . \tag{8}$$

For a two-dimensional digital image f(i,j), the discrete analog of the Laplacian is

$$\begin{aligned} \Box^2 f(i,j) &= \Delta_x{}^2 f(i,j) + \Delta_y{}^2 f(i,j) \qquad (9) \\ &= [f(i+1,j)+f(i-1,j)+f(i,j+1)+f(i,j-1)] - 4f(i,j), \end{aligned}$$

Note that equation (9) is proportional, by a factor -1/5, to

$$f(i,j) - 1/5[f(i+1,j)+f(i-1,j)+f(i,j)+f(i,j+1)+f(i,j-1)], \tag{10}$$

which is the difference between the gray level f(i,j) and the average gray level in a neighbourhood consists of pixel (i,j) and its four horizontal and vertical neighbours.

Thus the digital Laplacian of a picture f is obtained, up to a constant factor, by subtracting a blurred (i.e., averaged) version of f from f itself. In the matrix form, the Laplacian filter can be written, up to a constant, as

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

which can be convolved with an original image.

The edge detection and Laplacian were applied first to a RIDS radar image collected under a calm sea state (Figure 25). The image, was recorded in calm sea, the interference by sea clutter on the targets is considered as minimal. The image was processed by an edge detection filter and the resulting picture is shown in Figure 26. It is clear that much of the information was lost due to the fact that an edge detection type filter tends to disregard features with weak returns (compared with the surrounding region), which means small targets such as growlers and mush ice may be eliminated altogether from an image after the filtering. However, the Laplacian filter does not have this drawback. A Laplacian filtered version is shown in Figure 27. As can be seen, the Laplacian is effective in highlighting the icebergs, and this type of filter should be considered as a viable means to be implemented in future display systems to enhance marine radar images recorded in calm and smooth seas.

A procedure that has been implemented on the RIDS to reduce noise and to enhance target detectability is multi-scan averaging for a sequence of consecutive images. In Figure 28, a four-scan averaged image is displayed. The first notable feature is that the noise has increased considerably as a result of averaging, and the icebergs are hardly visible. The second feature is that the signal returns near the radar are stronger than returns far away due to the range dependent gain inherent in all radars. The severity of this range dependent problem may be reduced by a histogram normalization in the digital processing phase, or by an inverse range dependent gain function applied to images on RIDS in displaying phase.

Although the usefulness of multi-scan averaging has been successfully demonstrated in the field, it was shown that multi-scan averaging can be used to improve signal-to-clutter ratio for images collected in moderate and rough seas.

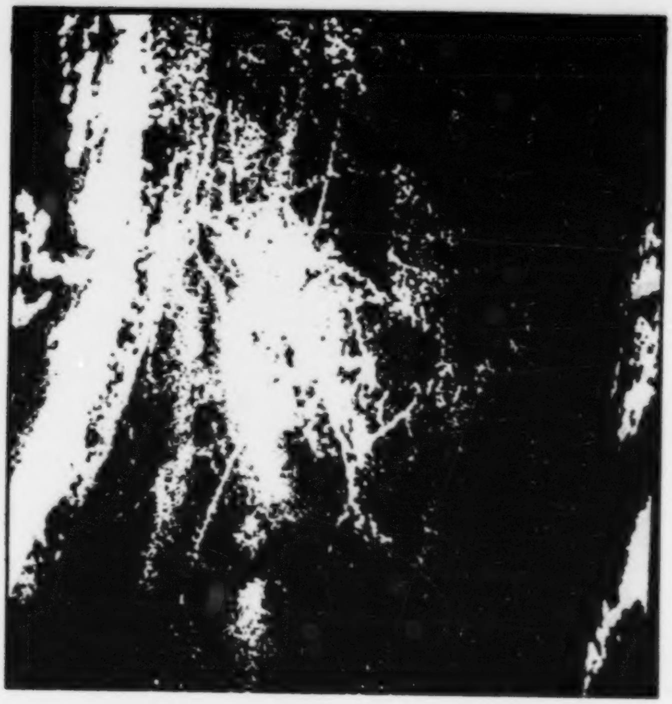


Figure 25 Single-scan image from calm sea state.

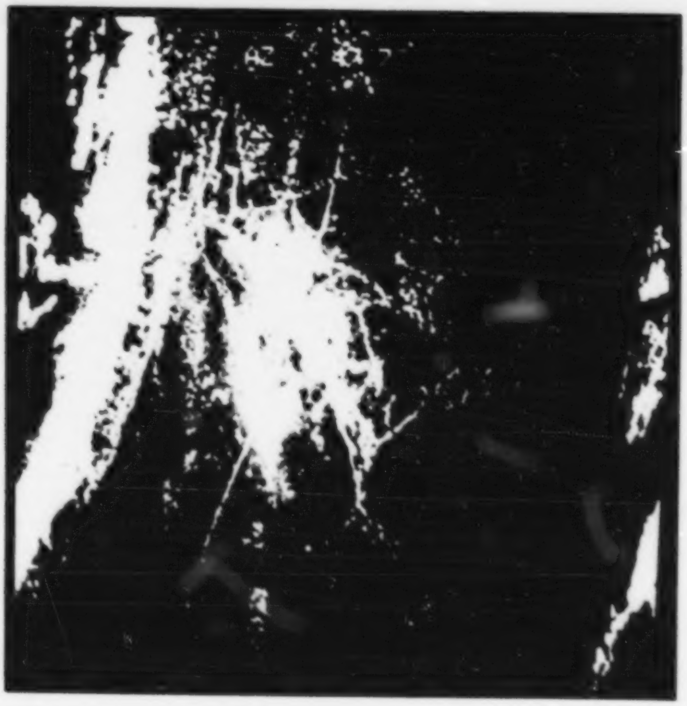


Figure 26 Single-scan edge detection image from a calm sea state.

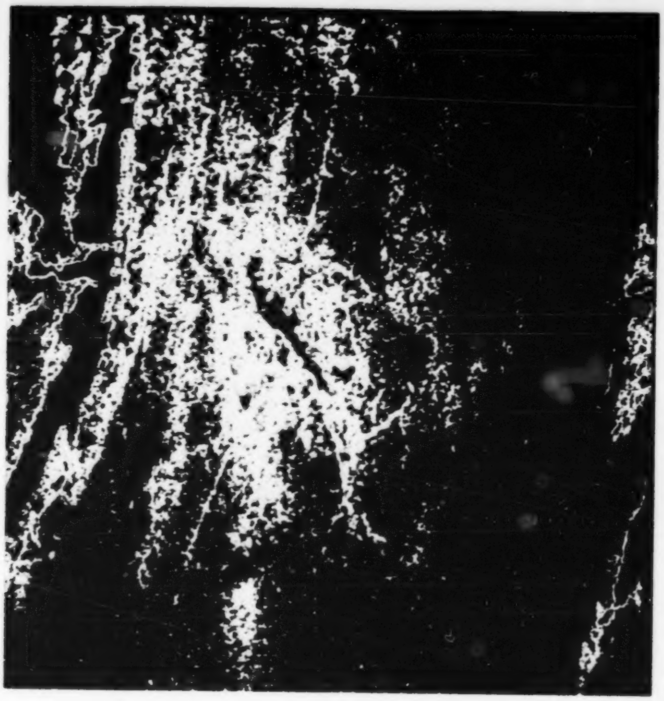


Figure 27 Single-scan Laplacian filtered image from a calm sea state.

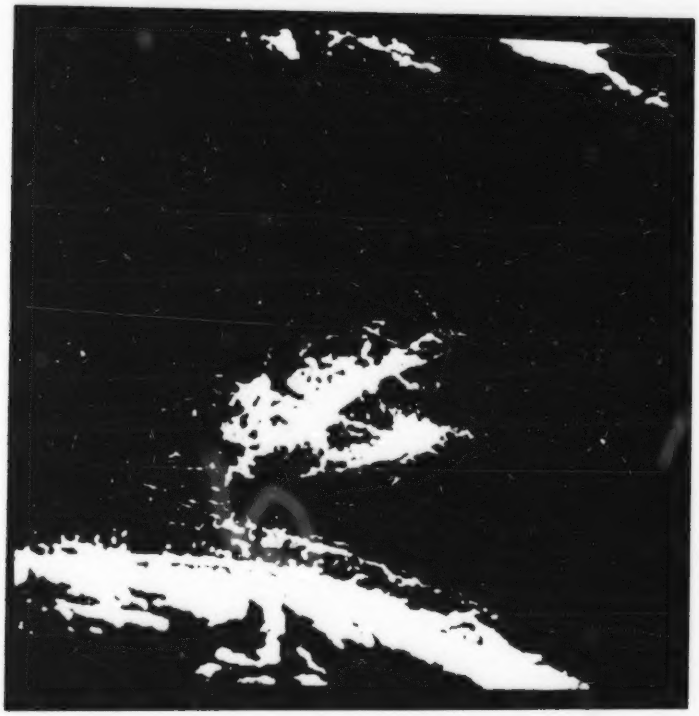


Figure 28 Four-scan averaged image from a calm sea state.

Conclusions

Although the research in this area was not meant to be exhaustive, it does illustrate the merit of using a digital display system and applying digital enhancement techniques. From our brief study, several observations can be made:

1. For radar images collected in a calm sea state, multi-scan averaging is not required. Due to the multi-pathing effect, a multi-scan averaging may not achieve desired improvement on signal-to-clutter ratio, as both the target and clutter returns fluctuate rapidly from one scan to another. However, in moderate or rough sea states, it is necessary to perform a multi-scan averaging on marine radar images prior to any other digital filtering.
2. The Laplacian filter is found to be suitable for iceberg feature enhancement. But it is ineffective in eliminating salt-and-pepper noise and sea clutter. On the other hand, the edge detection filter is well-suited for the purpose of cleansing the salt-and-pepper noise, as well as minor sea clutter from radar images.
3. Since most of the marine radar images are recorded on radial format, a scan conversion to rectangular format is required for each image. As a result, Moire patterns of negative spikes may be generated on the image diagonals due to unsampled pixels. The Moire patterns were visible in Figures 25 and 28. Median filtering was applied to some scan converted images, and the results indicated that the filtering was successful in suppressing the Moire patterns, but unfortunately, it also degraded the iceberg features. One of the better ways to eliminate the Moire patterns is to use a better analog-to-digital scan conversion device in the data recording stage. The marine radar data recorded on the Folsom system do not show any Moire patterns.
4. The Laplacian or edge detection filter should be considered only in the absence of knowledge about the nature of clutter and noise that are to be corrected. When such information becomes available, restoration methods such as inverse filtering should be used instead.
5. In order to make the above information available, further investigation and an in-depth understanding of sea clutter as a function of sea states and radar parameters are very much desired. From our brief examination it appears quite difficult to reduce sea clutter in the digital processing phase. It is entirely feasible though to reduce the clutter by implementing an anti-clutter device in the data acquisition stage, for example, scan averaging.

5.6 Expert Systems

The few techniques that were explored for post-processing the marine radar showed promise under some sea states and ice conditions. Because icebreaking ships operate in a variety of regions and under a variety of sea conditions, some form of adaptive radar signal processing would be desirable. Adaptive of course refers to the fact that the signal processing technique would "adapt" itself to the given sea state to provide the "best" picture of the displayed targets. A small study was therefore undertaken to determine whether the new expert system technology could be applied to this and several other marine radar problems. A commercial expert system shell called M1 was purchased and evaluated for this role.

Expert systems are a new method developed to solve difficult problems. Artificial intelligence in the form of heuristics applies human expertise to solve problems that previously were not tractable using conventional programming techniques. The basis for an expert system's success is its modular structure, independent control and heuristic knowledge.

Problems in marine radar and ice data interpretation, such as probability risk analysis, have been attempted using conventional programming approaches. Other problems such as adaptive processing, target detection and tracking have not. These problems need to be investigated to see if they have the necessary qualifications for expert systems development.

The purpose of the study reported here was to introduce the general concept of an expert system, evaluate M1 as a suitable expert system for developing applications, and review a series of marine radar and ice data interpretation and analysis problems for their suitability for expert systems development.

M1

M1 is an expert system tool of similar architecture developed by Tecknowledge Inc. of Palo Alto, California. It can be applied to the problems of diagnosis, analysis, planning, design and selection. These problems, however, must have specific characteristics to be selected for expert systems development.

This section discusses some basic expert system concepts that will aid in the evaluation of M1. For a complete discourse on the subject, the reader is directed to any text on expert systems.

Architecture

An expert system has three components: a working memory, a knowledge base, and an inference engine. The working memory represents the current problem state; the knowledge base represent the expertise used by the system. This expertise consists of if-premise-then action rules. The inference engine compares the working memory elements against the premises of the rules, and takes the corresponding action when they match.

This architecture produces modularity in an application development, because each rule is created and acts independently of the others. Deleting or adding a rule can be done easily, and its effects can be seen immediately, so a system can be quickly prototyped, modified and extended to its full potential.

Another advantage is that a complex problem can be simplified by subdividing it into separate cases, using a variety of heuristics that state how each separate case of the problem should be handled. Each expert system rule represents a different case of the problem and is applied only when the situation warrants it. A rule will then 'act' upon that situation using its declared procedures.

In contrast, a conventional program is created from one specific algorithm which can handle a limited number of cases. It executes statements in the order in which they are declared in the program, not when the situation requires it. It is less interested in declaring what knowledge is necessary to solve the problem than in how to proceduralize its limited knowledge into an efficient algorithm, a process that can be time consuming and difficult.

Because these two programming techniques approach problem solving differently, some applications are more suitable for expert systems development than others.

Expert System Terminology

An expert system makes inferences through a cycle of pattern matching followed by action. The first step in inferencing is to assert the facts contained in the knowledge base into working memory. The facts represent what the system knows initially about the problem characteristics. Then the inference engine tries to match a rule's premise against the working memory elements. When a match occurs, the rule's action can retract old working memory elements and/or assert new elements. Rules represent all inferred knowledge in the system. This cycle of pattern matching and making conclusions continues until a halting action is performed.

Knowledge representation describes the form of the facts and rules contained in the knowledge base. In a frame-based system, knowledge is arranged as a hierarchy of frames that describe objects and classes of objects. Frames are templates of information and contain slots that describe an object type. When an object of that type is created, slots are filled with actual values discerning that object from others of the same type or class. Rules are attached as procedures to individual objects, and are fired when a message is sent to a frame requesting information from the rule. In contrast, a rule-based system defines knowledge as independent facts and rules. There is no hierarchy and structures can take arbitrary forms, such as lists and parenthetic structures, unlike a frame representation. Frame-based systems are used in problems that require highly structured knowledge or knowledge that can be mapped onto a class hierarchy. Rule-based systems are more flexible and are used in problems where there is no knowledge hierarchy or the knowledge is ill-structured.

A knowledge base can contain two types of knowledge: domain specific (judgemental) and meta knowledge. Domain specific knowledge are rules and facts that directly assign values for expressions contained in working memory. Meta knowledge describes how the system will find values for expressions. Literally, meta knowledge means "knowledge about knowledge", and deals with the control of the expert system only. This can include, for example, deciding in what order the rules will execute.

Rules are constructed with two parts: a premise and an action. The premise of a rule consists of propositions that must be matched to elements in working memory for the action to be executed. The general structure is in one of two forms:

```
if   <proposition1> and if <proposition1> or
     <proposition2> and if <proposition2> or
     ...                   ...
     <propositionN>        <propositionN>

then <action1>    and then <action1> and
     <action2>    and      <action2> and
     ...                   ...
     <actionN>    and      <actionN>

       Case 1                Case 2
```

The **ands** in Case 1 form a conjunctive premise. All propositions must be matched against working memory elements for the action to execute. The **ors** in Case two form a disjunctive premise; only one proposition must match for the action to execute.

Propositions usually take the form of a parenthetic structure. The operator, the term outside the parenthesis, is the relation of the structure. The objects are the terms inside the parenthesis. The operator defines the unique prefix relationship among the objects inside. For example, mother(mary,john) is understood as 'mary is the mother of john'.

Propositions can contain variables. These variables can match with any literal of a working memory element. For example, the propositions mother(mary,X) and mother(X,Y), will match with the working memory element mother(mary,kevin). Facts cannot contain variables.

A rule cannot execute until all the variables in its propositions are matched with the literals of working memory elements. This procedure, called instantiation, replaces a rule's variables by their literal counterpart. Each unique instantiation creates a unique rule that can fire. Using the previous example, if there were two working memory elements, mother(mary,kevin) and mother(mary,bruce), then the rule proposition mary(mary,X) would be instantiated twice. In the first rule, X would be instantiated to kevin and in the second, X would be instantiated to bruce.

During an instantiation, a variable binding takes place that is local to the rule. If a variable is instantiated to a value, then whenever that variable is re-encountered in the rule, whether it be in later propositions in its premise or in the action part of the rule, that variable is automatically bound to the same value. For example, given the following rule and working memory element:

```
     Rule                           Working Memory Element
if

   mother(mary,X) and
   mother(X,kevin)                  mother(mary,margaret).

then

   grandmother(mary,kevin).
```

if proposition mother(mary,X) is matched against mother(mary,margaret), then X is bound or instantiated to margaret, and the following X is bound to margaret automatically. This forces the rule to match with a working element mother(margaret,devin). If that working element exists, the second proposition will match and the action part of this rule will fire.

The inference engine of an expert system works in one or two directions. A backward-chaining system places a single goal in the working memory whose value is unknown. The system applies one rule per inference cycle to conclude a value for this goal. If expressions in the premise of this rule also have unknown values, the system will recurse and enter the expressions as subgoals in working memory. It will then apply a nested set of rules to find values for the subgoals. The system returns to the start when the values for the goal and all subgoals have been found.

A forward-chaining system contrasts this procedure by starting with a thorough description of the problem state. All working memory elements have known values. In one inference cycle, every rule that has a match is held in a conflict set, from which one rule is selected to fire. Each rule that fires alters the problem state to produce a new one. The system stops when the desired halting problem state is recognized by a rule that will execute a halt.

Each type of system is suited to its own class of problems. Backward-chaining systems are used for diagnosis and prediction, forward-chaining for modeling and optimization.

Backtracking is a process unique to a backward-chaining system. Backward-chaining systems select rules in the order in which they appear in the knowledge base. The rule then has its variables instantiated against working memory elements. If an instantiation can be found for all propositions, the rule fires. If the instantiation proceeds partially down the list of propositions, but fails, i.e., a particular proposition cannot match with any working element, the system backtracks to re-instantiate a previous variable with a new value, in hopes that the system with its new bindings can instantiate the rest of the propositions. Usually, backtracking proceeds until one instantiation of a rule succeeds and fires.

In a backward-chaining system, a level of certainty can be given to an expression's value when it is asserted into working memory. Certainty factors indicate how truthful (a positive number) or false (negative number) a value is. Zero is reserved for neutrality and an arbitrary positive number and its negative inverse represent the absolutely true and false. If an expression is used in the premise of a rule to conclude about the value of another expression, its certainty factor is included into the certainty calculation for the new expression.

Technical Summary

M1 is an expert system tool having the same architecture as the one described above. M1 is a backward-chaining system, and supports a rule-based knowledge scheme only. Values for expressions can be single or multiple and can be made up of atoms, numbers, or complex data structures which include lists (e.g.[a,b,c,d,e]) and parenthetic structures (e.g. mom(mary,john)). A certainty factor can also be tagged to value of an expression.

M1 has a limited capability for declaring meta knowledge in the system. This includes constructs to give explanations when required, follow certain procedures when a value is found for an expression, and pose a question for a user response if a value has not been found by the system's rules. Meta knowledge can either be entered directly as facts or as propositions in the premises of rules.

A presupposition construct can be used to control the search process by defining 'pre-search' conditions that must be true before value is searched for an expression. It is used to halt a search on an expression whose value will still be unknown after the search has concluded.

M1 exhibits a property called 'single value cutoff'. When an expression is single valued, the system can give only one value for it at the end of a consultation; however, M1 will keep track of all the expression's uncertain values until one absolutely true or false value is found. From this point on, a single value is kept for that expression. This property disallows the system from changing that value to a new one if the new value's certainty is less than absolute.

To make code more readable, M1 allows the developer to declare his own operators, making them either infix, prefix, or suffix. Operators can also be declared to be strings or words instead of one hyphenated word. So hard-to-read propositions, such as is-between(a,b) can be changed to the more readable version 'a is between b'.

M1 performs backtracking differently from the standard form in two ways. First, every time a disjunctive proposition is satisfied as a rule's premise, the action of the rule is performed. If there are n disjunctive ways of satisfying the premise, the conclusion will be asserted **n** different times. Usually when a disjunctive proposition is satisfied, the rule fires only once. Second, if more than one instantiation of a rule can be made, the system will backtrack across each different instantiation forcing the rule to execute each time. Thus M1 backtracks to find and act upon all possible combinations of a rule's execution. Usually, backward-chaining systems find just one instantiation and act on it.

M1's Abilities and Limitations

M1 is implemented in 'C' and can access other functions written in the same language. It can be used with other products to access file and database information. Thus, M1 can restrict its use to non-procedural applications and leave the number crunching and information storage to other packages that do this efficiently.

M1 has no graphics capability; its input and output is only textual. This will necessarily restrict the type of information that can be given to or used by the system.

M1 can support a knowledge base of up to 1000 rules, which will allow development of a large program. However, M1 does not support multiple knowledge bases and there is a disadvantage to all expert systems in that the larger the knowledge base, the slower the program execution.

As a general applications development tool, M1 can be used to build systems that solve five types of problems:

1. Analysis - monitoring streams of and interpreting trends found in data;
2. Planning - building customized plans using generic subplans contained in a library;

3. Design - customizing a chosen design schemata for inclusion in a larger design;
4. Selection - mapping a user's terms onto a catalogue's or database's terms for information retrieval; and
5. Diagnosis - providing advice on what is wrong with a piece of equipment.

Backward-chaining systems, however, are typically used for diagnosis applications only.

Problem Characteristics for M1 Development

Certain problems are best suited for conventional program development, others for expert systems development. Some points and general guidelines are given below for selecting an appropriate problem for development using M1.

1. A human expert should be able to solve the problem in about half an hour.
2. No direct physical contact with other equipment should be required to solve the problem.
3. The solution should involve judgemental reasoning only and not rely solely on extensive calculations or formal analysis.
4. The problem should be able to be broken into a few discrete subproblems.
5. For each subproblem, there should be no more than a few dozen possible conclusions.

Point number two can be ignored if the user and the developer agree as to what equipment will be used during a consultation. Point three can be relaxed if an expert system is built as a front end for a computationally intensive program as an aid in selecting its parameters. Points four and five are the most important and should not be ignored.

The problem should be one that is already well understood by someone in the organization; someone that could be used as an expert. Barring that, at least one person in the organization should be able to perform the task well. The knowledge and the consensus on a competent solution will be extracted from one of these people.

The solution should be heavily dependent upon the knowledge or experience that the expert has. Problems that are computationally intensive are not good candidates. Problems which have a high variability in peoples' ability to solve them are. If experience gives a person the edge to solving the problem, it is likely that heuristic knowledge is being used to solve it and is therefore a prime candidate for being developed as an expert system.

Other sources of knowledge can include texts and journals. Their general methods of problem solving can be encoded as knowledge in the system. The detail in reference books should be reserved for later in the development process to refine the knowledge that is already present in the system.

The facts and terminology to be used by the system should be accessible and understood by the user. Accessibility also includes that to any equipment, printouts, statistical data, etc., that the user will need to solve the problem.

The facts of a problem should be stable for the duration of a consultation. Systems that reason about a problem while its characteristics are continually changing are more difficult to develop that those that do not.

The final guideline that can be used to select an appropriate problem is the "telephone test". Is the problem one in which a competent person can help the intended user over the phone? This means that a dialogue is sufficient to capture the problem's characteristics. If any other type of perception is required, for example, three-dimensional perception, then the task fails the telephone test, unless the person and the user can communicate their perceptions through the dialogue unambiguously.

An Evaluation of Marine Radar

The purpose of this report was to introduce expert systems with the intent of developing an application pertaining to marine radar systems. Three problems are discussed in this section with regards to their suitability for expert systems development: target detection and tracking, pre-processed signal processing, and probability risk analysis.

Target Detection and Tracking

The problem of target detection and tracking is that given a radar image of a sea scape, detect the existence and track the motion of certain hazards in the water for the purpose of navigating a ship around them. Hazards can be, for examples, icebergs and other ships. An expert system would be used to initially detect and track the target and suggest maneuvers to avoid the hazards.

For this problem, two questions must be answered. What pattern matching facilities are necessary to solve this problem and what expertise is available in ice transiting?

Target detection is one of the more difficult classes of artificial intelligence problems since it involves the task of pattern matching. The difficulty is that given one object, several patterns can be generated from it, all of which should be recognized by the system. An expert system may be programmed to match on only one pattern and have a good translation mechanism to map 'similar' images onto the one stored pattern. If there is no translation mechanism, many patterns must be stored. M1's execution speed will suffer with an excessively large knowledge base, so an adequate translation mechanism should be developed.

To simplify the problem further, the search of the image and the number and type of possible targets to be recognized by the system should be scaled down. Yan (2) in his expert system for land-marking cephalograms subdivided an x-ray image to simplify the search problem. The system first enhanced possible patterns by post-processing the image and then subdivided the total image. It used frame-based knowledge to model known landmark configurations to match it against the enhanced ones found on the image subareas. The knowledge base included information on the height, width, and angle of the landmark, and in which subarea of the image the landmark was likely to be found.

This same approach could be taken with target detection and tracking. The image could be subdivided to reduce the search area so that pattern matching over a smaller area could be more complete and probably more successful. The knowledge base would include information on targets such as possible sizes, usual locations and usual rate of movement. Tracking knowledge would include target locality and actual rate of movement through several images. Because M1 does not support frame-based knowledge, the knowledge base will have to be well-structured if this problem is to be manageable.

It the initial target detection is too difficult, the expert system could be given the targets as input and then required to track only. Knowledge on usual rates of movement and the locale of the object in succeeding images could be used to track the target. Tracking would probably require a smaller knowledge base than detection would.

Overall, target detection and tracking is a difficult problem to solve, but one which, if it eventually worked, would be invaluable to many organizations.

Signal Processing

The problem of signal processing is that given an incoming sample signal, it must be pre-processed to display wanted information only. The expert system for this problem would be used as a front end to the actual pre-processing program. It would select the best pre-processing parameters based upon the quality and characteristics of the sample signal and pass them as constraints to the pre-processor.

The major problem with this application is that the expert system must work in real-time. M1 does not seem to be a good tool for this; it may not even be possible. It depends upon the rate at which the signals are coming in and the sampling rate required of the expert system.

If M1 can work in real-time for this application, its knowledge base cannot be large. Its decisions should be based on a few concise heuristics that will select the best pre-processing parameters for a signal.

M1 has no problem interfacing with other applications for the purposes of constraint propagation. For example, Tecknowledge's SACON (Structural Analysis Consultant) (3) was built using M1, and gives expert advise on selecting parameters and procedures for another program that performs the analysis. This application, however, was not done in real-time.

If the expertise is available for this application, which it most likely is, this problem does not seem very difficult to solve except for its real-time constraint.

Probability Risk Analysis

Probability risk analysis is the process where design criteria and ice avoidance probabilities are calculated using a complex simulation model of a ship transiting through ice hazards. The simulation model requires information on ice feature sizes, ice monitoring systems, weather visibility and vessel maneuverability. The uncertain nature of some of the information requires it to be modeled by a probability distribution function. An expert system would be developed to simulate this using heuristic knowledge instead of probability.

This problem seems highly "knowledge intensive" and an expert system implementation would have many benefits over the conventional program. Heuristics taken from ice piloting handbooks could be easily compiled as knowledge in the expert system. M1 could reason about the uncertainty of some parameters by using certainty factors instead of probability density functions. Previously unusable factors, such as crew experience, could now be coded as knowledge in the expert system.

The only drawback is that given the complex nature of this problem, the knowledge base will have to be large to analyze a situation competently let alone expertly. The size of this problem will also entail a highly structured and well organized knowledge base, so that the continuing development of the application could be easily controlled and understood.

This problem may have fewer drawbacks than the others, the main one being how to organize the large amounts of knowledge required to solve it. It may be interesting to investigate simulation using heuristics.

Conclusion

To sum up, expert systems are a viable way of solving complex problems, if the problems have the necessary characteristics to be developed as one. M1 is a good expert system tool as long as it is used within the constraints imposed by its implementation. Mainly, these include that the application not have too large a knowledge base and not have to be executed in real-time. Finally, any one of the three problems dealing with marine radar systems and ice data interpretation and analysis could be developed as an expert system, if their fundamental implementation problems can be overcome.

5.7 Conclusions and Recommendations - MARINE-VUE

From all the above mentioned TDC-sponsored research and development, it is clear that the requirements for the MARINE-VUE marine radar display system are now firmly established. They can be summarized as follows:

1. The system must present marine radar data on a bright TV-type display. This display should refresh in real time and allow an individual image to be frozen on the display for any length of time.
2. The system should be able to interface to any radar without overriding the normal radar controls.
3. The system should display both north up and ship's head up radar data.
4. The image should be displayed with the normal radar ranges of 0.75, 1.5, 3, 6, 12, 24 and 48 nm.
5. The display must have at least 2 bit of video display and should have a choice of colour or black and white presentation.
6. It should have the normal radar signal processing such as STC and FTC available.
7. The user interface should have controls that are similar to or emulate those of a standard radar. It must be easy to use by ship's crew, ice observers and those familiar with radar systems.
8. The system must have a standard computer interface so that data can be shared with other computer systems.
9. The equipment must be reliable and robust and suitable for mounting on the bridge of a ship.

During the time frame of this project, several radar display systems have been tested and evaluated. It was determined that the RIDS system would have to be redesigned to perform the majority of its functions in hardware. This, however, would require a major redesign and equipment build. During the summer of 1986 a new radar scan converter manufactured by a company called Folsom Research was tested on the M.V. Arctic. The Folsom unit was found to be a much higher quality display unit than the RIDS or the JRC units, which were used for comparison. This is because the Folsom unit displays every radial pulse and writes an extremely high quality display result into memory. In addition, the

Folsom unit has a standard computer interface which can be controlled from the STAR-VUE host computer. Both control signals and data can be exchanged. A menu system was developed for the STAR-VUE to control the Folsom unit for this program. Although the Folsom unit proved to be the best available display system for MARINE-VUE, several features were found to be lacking. These features include:

1. A "stand-alone" interface that is easy to use for controlling all radar functions;
2. An interface to the ship's gyro for ship's heading mark;
3. An adjustable range and bearing cursor;
4. A front panel and computer control for intensity, gain and threshold;
5. Clutter removal circuits (STC,FTC); and
6. Range rings.

In addition, several desirable features could be added to improve the utility of the system. These include user selectable scale settings beyond the ranges of 3, 6, 12 and 24 n.mi. scales and some form of scan averaging.

Many of the functions mentioned above are additions which Folsom plans to add to their system. Some require future research and development. Despite the limitations of the current technology, several important points need to be reiterated.

The use of SAR imagery delivered for support of tactical ice navigation can be enhanced by comparison with the ship's own marine radar data. The marine radar provides an exact ship/ice location and can be used to update the position of the ship between SAR flights.

The marine radar display used as the MARINE-VUE component for a NAV-ICE workstation must be a bright, softcopy display like the Folsom unit purchased by Transportation Development Centre (TDC). This Folsom unit exhibits most of the needed characteristics required of such a system. However, further developments are needed.

Continued research and development in this area will result in the provision of a system to meet the needs of the marine community for the task of ice navigation as well as provide a fully commercial system which can be used for many other applications requiring radar data.

The use of computer-based scan converters has many advantages over the standard radar PPI displays. Not only do these systems provide a bright persistent display, but they also make data available in a form that can be integrated with radar and other sensor data, e.g., HH, HV polarized radar, sonar, etc. A Folsom device, for example, is planned to be used to display the data from both a horizontally and vertically polarized radar on the M.V. Arctic this year. The horizontally polarized data will be assigned one colour and the vertically polarized data will be assigned another colour. A system like STAR-VUE can also be used to display data from a number of these different sensors on a single display. Data integrated from several sources and sensors can potentially provide a ship with much more useful information on ice conditions and hazards than with, for example, that available from a single sensor.

Once the radar is in a digital format, it is possible to use digital processing techniques to improve the display quality and enhance target detection. Target tracking and other advanced features can also be implemented in software.

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APPENDIX A

MARINE VUE (PHASE I) FUNCTIONAL SPECIFICATION

ISSUE 1.1

OBJECTIVE:

This document will describe the changes in the STAR-VUE software required to support Folsom Box control from the track-ball. It is intended as a review document to establish what is going to be implemented as well as a guide to the software implementer.

OVERVIEW:

The Folsom box will be connect to the STAR-VUE host computer via a standard RS232-C communication cable. The cable will terminate at a DLV-E1 interface within the backplane of the 11/73 computer. Character codes will be passed across the link to alter the control setting stored in the Folsom box. A new piece of software will be required to drive the characters down the link. It is likely that this code will have to connect to the device through the I/O page and service it's own interrupts as the current STAR-VUE operating system does not have any DLV's sysgen'ed into it. The function of this software will be pass a character string received as the program arguments down the RS232 line. Since some sequences require imbedded escapes, there is a need for meta-character processing of the command line.

A new active button will be added to the Main Menu on STAR-VUE. This button, entitled MARINE VUE, will invoke a second level menu containing the various control types, of which there are eight.

1. FREEZE CONTROL
   This button will select a third level menu allowing the "Freeze Display" function to be turned on or off.
2. ANNO CONTROL
   This button will select a third level menu allowing the annotation to be place onto or removed from the display.
3. SET RANGE
   This button will select a third level menu allowing the selection a number of preset range values.
4. FADE CONTROL
   This button will select a third level menu allowing the selection a number of preset fade time values.
5. SET OFFSET DISTANCE
   This button will select a third level menu allowing the selection a number of preset offset distance values.
6. SET OFFSET ANGLE
   This button will select a third level menu allowing the selection a number of preset offset angle values.
7. CLEAR
   This button will cause the Folsom display to be cleared.
8. DISPLAY MODE
   This button will select a third level menu allowing the selection of "Average" or "PPI" display mode.

MARINE VUE menu

BUTTON	DESCRIPTION
FREEZE CONTROL	transfer to FREEZE CONTROL menu
ANNO CONTROL	transfer to ANNO CONTROL menu
SET RANGE	transfer to SET RANGE menu
FADE CONTROL	transfer to FADE CONTROL menu
SET OFFSET DISTANCE	transfer to SET OFFSET DISTANCE menu
SET OFFSET ANGLE	transfer to SET OFFSET ANGLE menu
CLEAR	issue <ESC>K
DISPLAY MODE	transfer to DISPLAY MODE menu

FREEZE CONTROL Menu

BUTTON	DESCRIPTION
FREEZE ON	issue a <ESC>G
FREEZE OFF	issue a <ESC>g

ANNO CONTROL Menu

BUTTON	DESCRIPTION
ANNO ON	issue <ESC>N<ESC>O
ANNO OFF	issue <ESC>n<ESC>o

SET RANGE Menu

BUTTON	DESCRIPTION
3 NM	issue <ESC>R3E
4 NM	issue <ESC>R4E
5 NM	issue <ESC>R5E
6 NM	issue <ESC>R6E
7 NM	issue <ESC>R7E
8 NM	issue <ESC>R8E
12 NM	issue <ESC>R12E
16 NM	issue <ESC>R16E
24 NM	issue <ESC>R24E

FADE CONTROL Menu

BUTTON	DESCRIPTION
OFF	issue <ESC>F0E
1 SECOND	issue <ESC>F1E
2 SECONDS	issue <ESC>F2E
4 SECONDS	issue <ESC>F4E
7 SECONDS	issue <ESC>F7E
10 SECONDS	issue <ESC>F10E
20 SECONDS	issue <ESC>F20E
30 SECONDS	issue <ESC>F30E

SET OFFSET DISTANCE Menu

BUTTON	DESCRIPTION
1 NM	issue <ESC>D1E
2 NM	issue <ESC>D2E
3 NM	issue <ESC>D3E
4 NM	issue <ESC>D4E
5 NM	issue <ESC>D5E
6 NM	issue <ESC>D6E
7 NM	issue <ESC>D7E
8 NM	issue <ESC>D8E
9 NM	issue <ESC>D9E

SET OFFSET ANGLE Menu

BUTTON	DESCRIPTION
0°	issue <ESC>A0E
45° RIGHT	issue <ESC>A45E
90° RIGHT	issue <ESC>A90E
135°	issue <ESC>A135E
180°	issue <ESC>A180E
45° LEFT	issue <ESC>A315E
90° LEFT	issue <ESC>A270E
135° LEFT	issue <ESC>A225E

DISPLAY MODE Menu

BUTTON	DESCRIPTION
AVERAGE MODE	issue <ESC>a
PPI MODE	issue <ESC>i

COMMUNICATION WITH FOLSOM BOX

As indicated in the overview, STAR-VUE will control the Folsom Box through an RS232-C port. The software interface will involve a task named "MVU". This task will

1. receive a series of command line arguments
2. process them appropriately to remove meta-characters
3. concatentate the processed arguments and output a command string to the Folsom Box.

The syntax of the MVU command will be as follows:

```
MVU  arg1  arg2  arg3  ...  argn
```

where 'arg1' to 'argn' are character strings representing the sequence of the command to be sent to the Folsom box. Each argument is drawn from the set of the printable ASCII characters. Certain characters have meaning other than themselves in order to allow the production of arbitrary character sequences. All alphabetic characters will be translated to their upper case equivalents unless otherwise modified by meta-characters.

If an argument to MVU contains with one of the following characters, then the corresponding actions are taken.

#	Insert a blank into the command sequence. All other characters in the argument are ignored.
@	The character following the '@' sign is processed literally, not as a special meta-character. Thus the pair of characters '@#' within a command string would result in a single # character.
$	Substitute the '$' character with an <ESC>
~	Force the character following the '~' to its lower case equivalent